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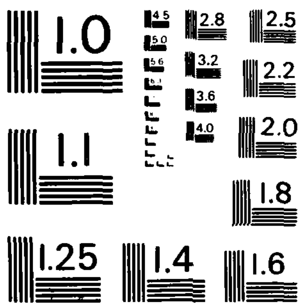

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Monterey, California

THESIS

DUAL-PHASE NOZZLE FLOW

by

Thomas C. Mollie, Jr.

October 1982

Thesis Advisor: J. F. Sladky

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Dual-Phase Nozzle Flow

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

A review of the dual-phase power system was made. This study focused on the multi-component nozzle of this dual-phase system. First, an existing computer code predicting the nozzle performance was updated, and second a series of experimental tests on a variable area, two-dimensional nozzle was performed to verify the computer code.

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I. DUAL-PHASE CYCLE

The dual-phase nozzle is a key element in the dual-phase engine concept. This nozzle will be studied in detail, but first a review of the dual-phase cycle will be carried out from information obtained from References 1 and 2.

Reference 1 describes the dual-phase engine. It is a new concept which operates on a mixture of two fluids or two phases of one fluid. This cycle employs a high-torque/low-rpm impulse turbine which eliminates the requirement for speed reduction needed in a conventional steam turbine. This allows for direct drive of a ship's propeller with no gear reduction. This is ideally suited for marine propulsion, reducing weight, noise, and volume.

The dual-phase concept is a modified Rankine cycle with subtle differences of extreme importance. In a normal steam turbine the working fluid enters a turbine through a nozzle where the kinetic energy of the working fluid is converted to a mechanical form. The dual-phase system introduces a second fluid prior to entry into the nozzle. This fluid is of higher vapor pressure than the steam and therefore remains in the liquid state throughout the cycle. Section A will describe this two-component cycle while section B will do the same for a single-component system. The dual-phase

system can be divided into the two groups illustrated in Figure 1. Single-component flow can be further divided into three categories.

A. TWO-COMPONENT

A two-component mixture is one in which the low vapor pressure liquid and a high vapor pressure liquid are of different chemical compounds. Some fluid combinations which have been considered are steam-krytox, steam-caloria, steam-lead, bismuth eutectic, and dow-therminol. A schematic flow diagram and process representation on the T-S diagram are shown in Figures 2 and 3 for the two-phase engine cycle using a "two-component" mixture. The liquid phase is lithium carbonate and vapor phase is steam. To illustrate the overall advantages of the two-phase engine cycle a discussion on the theory of operation will be presented using a two-component mixture and Figures 2 and 3.

The major component of the dual-phase system is the nozzle. A mixer area is located prior to the nozzle inlet. A high vapor pressure liquid is placed in contact with the low vapor pressure liquid in this area. A high pressure vapor liquid mixture is formed. Since the temperature of the liquid is greater than temperature of the water, heat is transferred to the water causing it to vaporize to point 1. Figure 4 illustrates the temperature and state point from the inlet of the mixture area to the nozzle exit. This mixture is

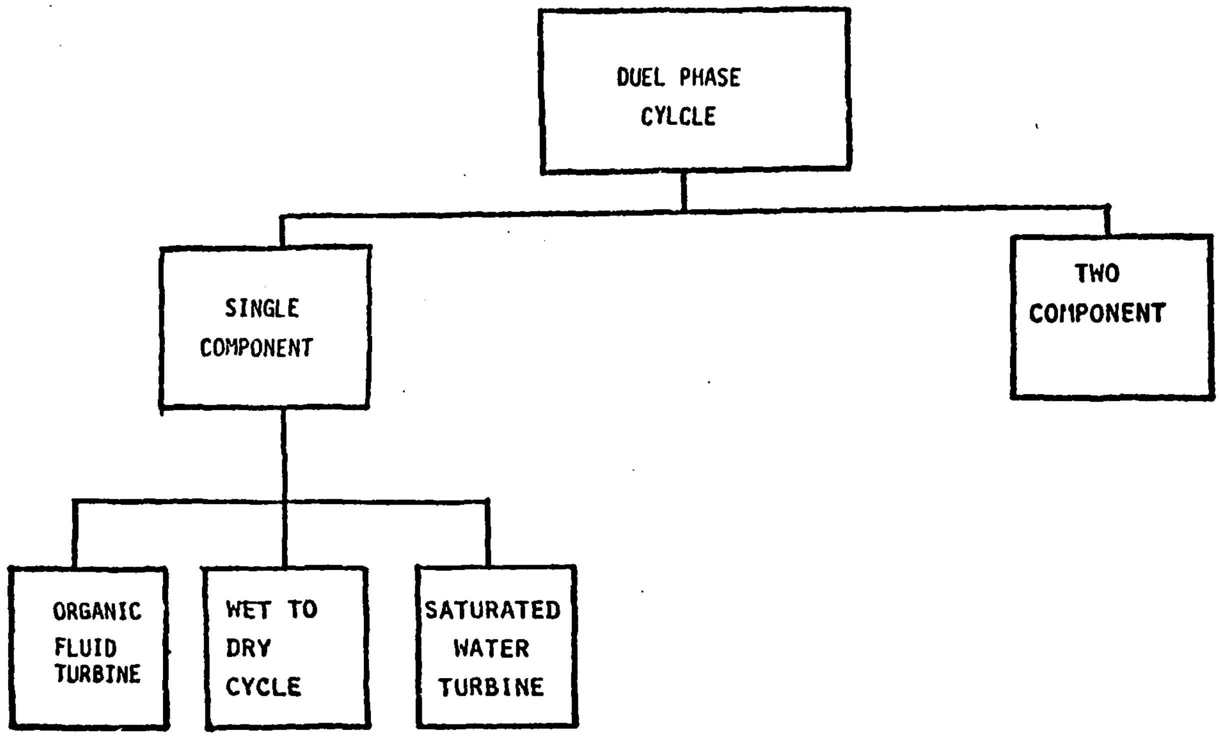


Figure 1. Division of the Dual-Phase Cycle

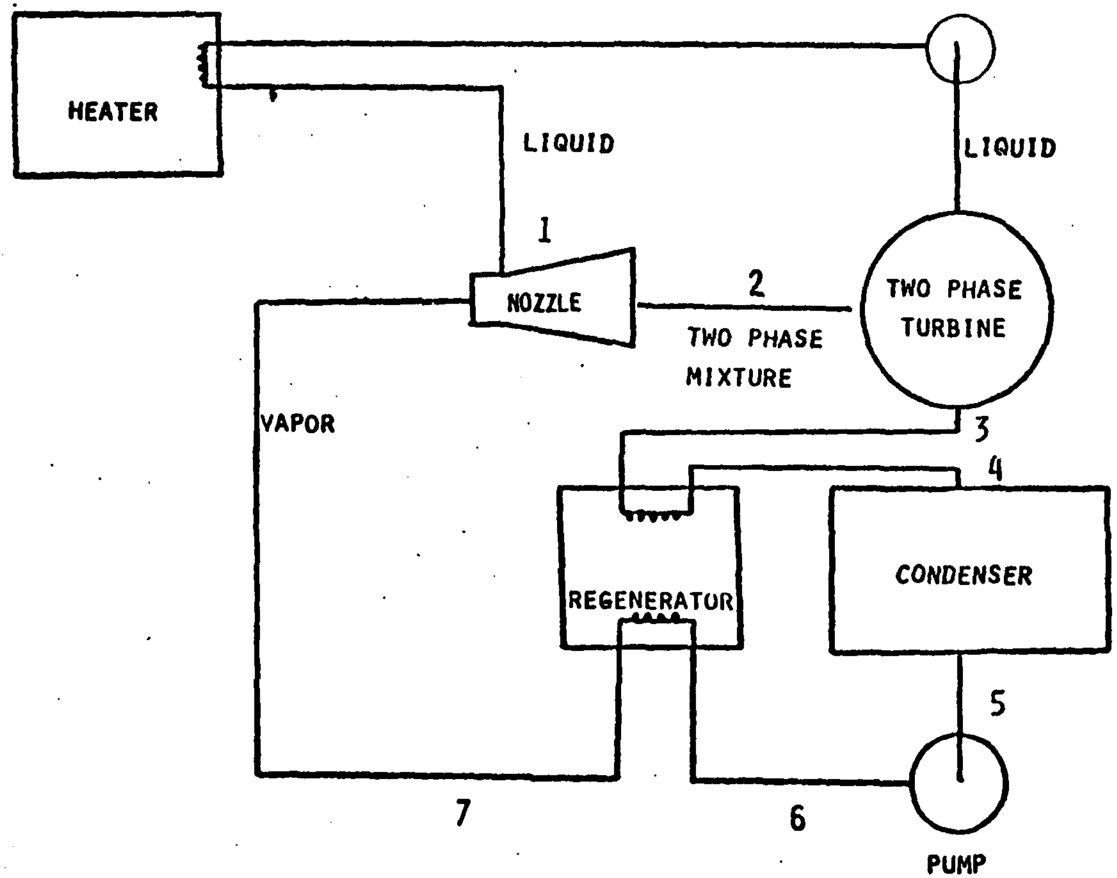


Figure 2. Dual-Phase Two-Component System

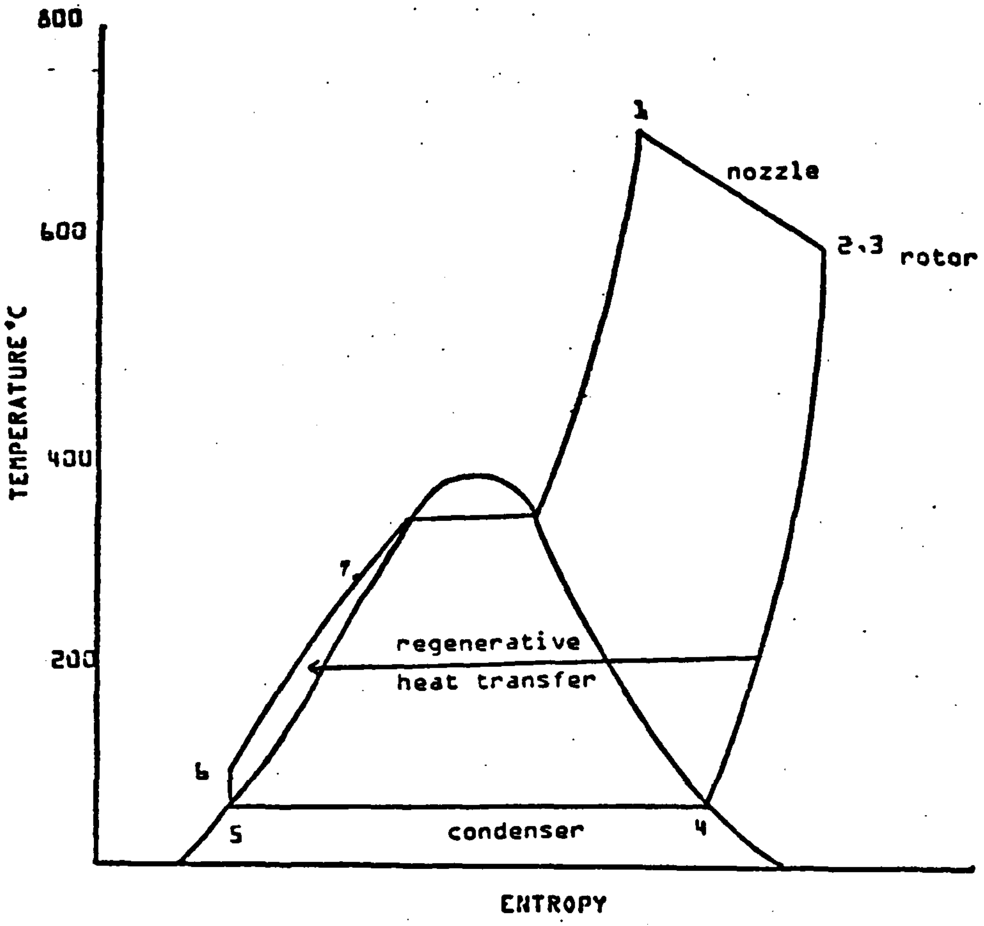


Figure 3. Dual-Phase Two-Component T-S Diagram

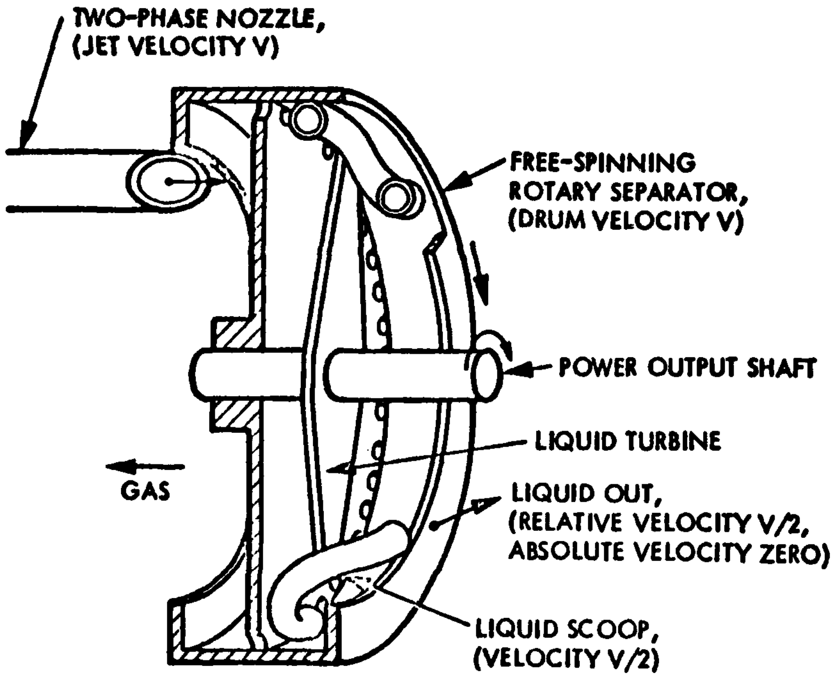
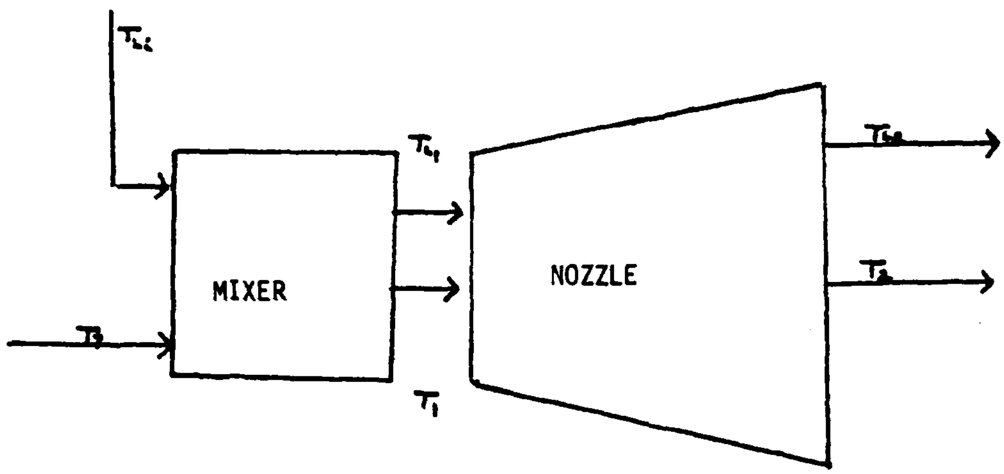


Figure 4. Liquid Impulse Turbine Schematic

expanded to a low pressure at the nozzle exit. The expanding vapor transfers momentum to the liquid droplets, while the droplets transfer heat to the vapor. This tends to apaproach isothermal expansion through the nozzle, point 2. After leaving the nozzle, the liquid droplets are separated from the vapor by a rotary separator located on the turbine. The rotating drum turns at close to the nozzle's exit velocity. Hence there is very little friction loss between the separated liquid and the drum wall. The centrifugal acceleration produces a very clean separation of vapor and liquid. The liquid traveling with the rim of the rotating drum transfers axially through holes in the separator disc and subsequently enters the liquid turbine proper. The kinetic energy of the liquid is converted to shaft horsepower by the liquid turbine. Figure 5 illustrates the dual-phase liquid impulse turbine assembly. The vapor remains superheated as a consequence of the heat transfer from the liquid. The vapor flows from the separator, point 3, through a regenerator where heat is transferred to the condensate. The vapor is condensed, point 5; pumped to nozzle pressure, point 6; and passed through the regenerator for heating. Heat is added between point 6 and point 1 in two methods. The regenerator adds heat to the condensate by using the steam from the turbine rotor, point 7. The remainder of heat, point 7 to 1, is added by the heated liquid mixed with the condensate in the mixer. The water is vaporized by direct-contact heat transfer.



where T_{L_i} = Temp of liquid entering mixer

T_7 = Temp of water entering mixer

$T_{L_i} > T_1$

T_2 = Temp of steam leaving the nozzle

T_{L_2} = Temp of liquid leaving the nozzle

Figure 5. Temperature & State Point Diagram for the Mixture & Nozzle

In the nozzle most of the thermal energy of the steam is converted to kinetic energy of the liquid droplets. This acceleration of the liquid by the vapor in the two-phase nozzle provides the kinetic energy to drive the liquid impulse turbine. The liquid velocities involved are relatively low as compared to velocity of the vapor. Thus, the output of the impulse hydraulic turbine will be high torque/low rpm. This conversion of the liquid kinetic energy to shaft power at high torque with low rpm appears to have direct application to naval propulsion.

B. ONE-COMPONENT

A one-component system is one in which the working fluid is of the same chemical compound. One of the simplest dual-phase one-component systems is illustrated in Figures 6 and 7. The working fluid is heated to saturation temperature by some type of heat source. Heat sources applicable to this case are geothermal power plants, engine exhaust, industrial waste-heat recovery, and bottoming cycles for steam and gas turbine plants. This working fluid, at saturated liquid conditions, with small amounts of vapor is expanded through a two-phase nozzle. As the expansion process takes place ,the liquid partially vaporizes and accelerates the remaining liquid phase in the nozzle. The dual-phase mixture enters the rotary separator and the same process occurs as mentioned in section A. Since the liquid phase is of a much higher

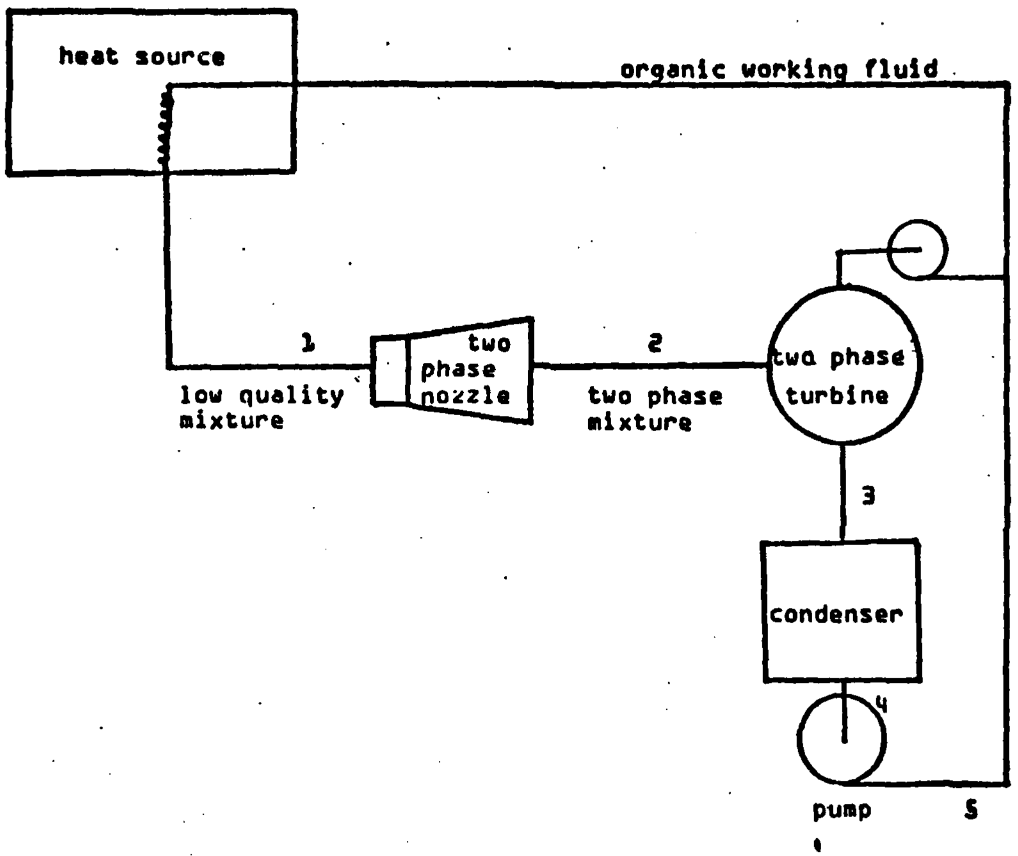


Figure 6. Dual-Phase Single-Component System

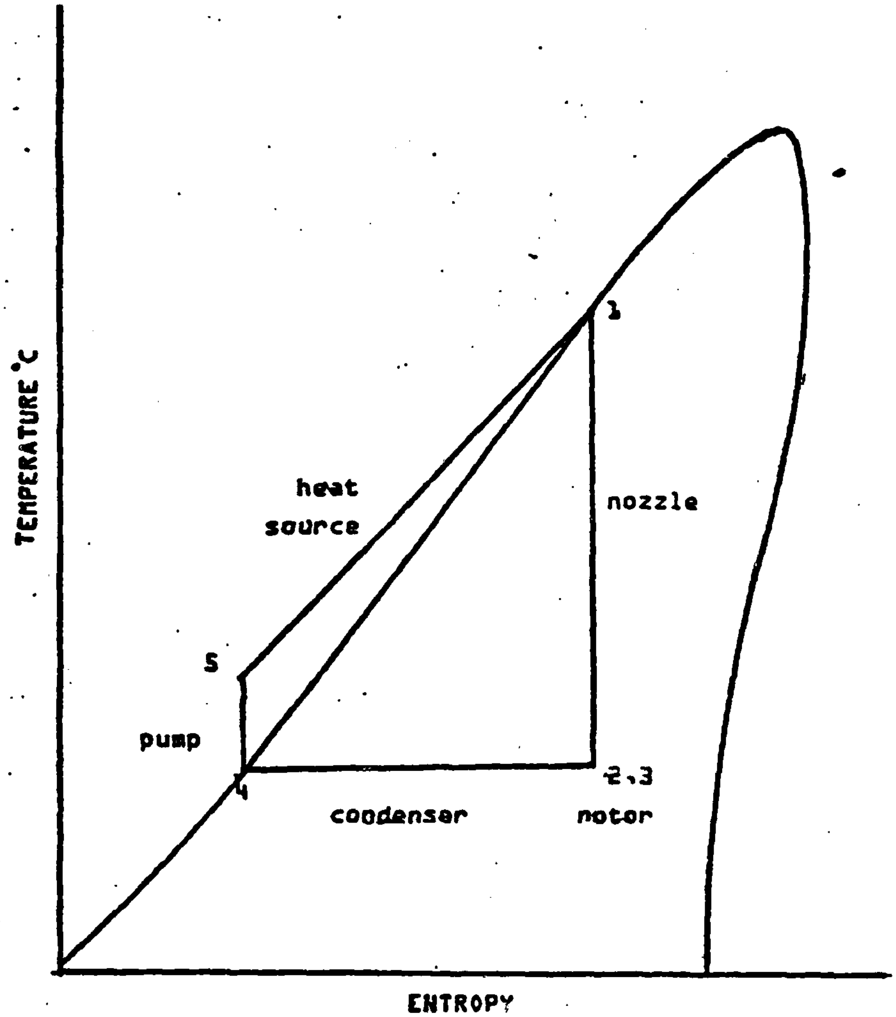


Figure 7. Dual-Phase Single-Component T-S Diagram

density than the vapor, the liquid velocities are relatively low as compared to the velocity of the vapor. Thus the output of the turbine will again have high torque at low rpm. After leaving the turbine the vapor mixture is condensed and the condensate is pumped back to the heat source. The cycle is shown on a T-S diagram in Figure 6. The state points are numbered to correspond with Figure 5. The dual-phase nozzle expansion takes the fluid from a saturated liquid, point 1, to a dual-phase flow, point 2. The flow is decelerated in the rotor; condensed, point 4; and pumped back to nozzle inlet pressure at point 5. The liquid is then reheated by the source fluid to point 1.

Another application of the one-component two-phase cycle is the wet-to-dry cycle. If the initial temperature of the working fluid is sufficiently high and the saturation curve has a positive saturated liquid slope the working fluid can be expanded to dry vapor. Figure 8 is the T-S diagram for a wet-to-dry cycle. The fluid is expanded from saturated liquid at point 1 to saturated vapor at point 2. The vapor drives an impulse rotor and leaves the rotor slightly superheated at point 3. The vapor is condensed to point 4 and pumped back to the nozzle inlet pressure at point 5.

C. ADVANTAGES

The advantage of the dual-phase cycle with respect to marine application is the ability to achieve low shaft speed

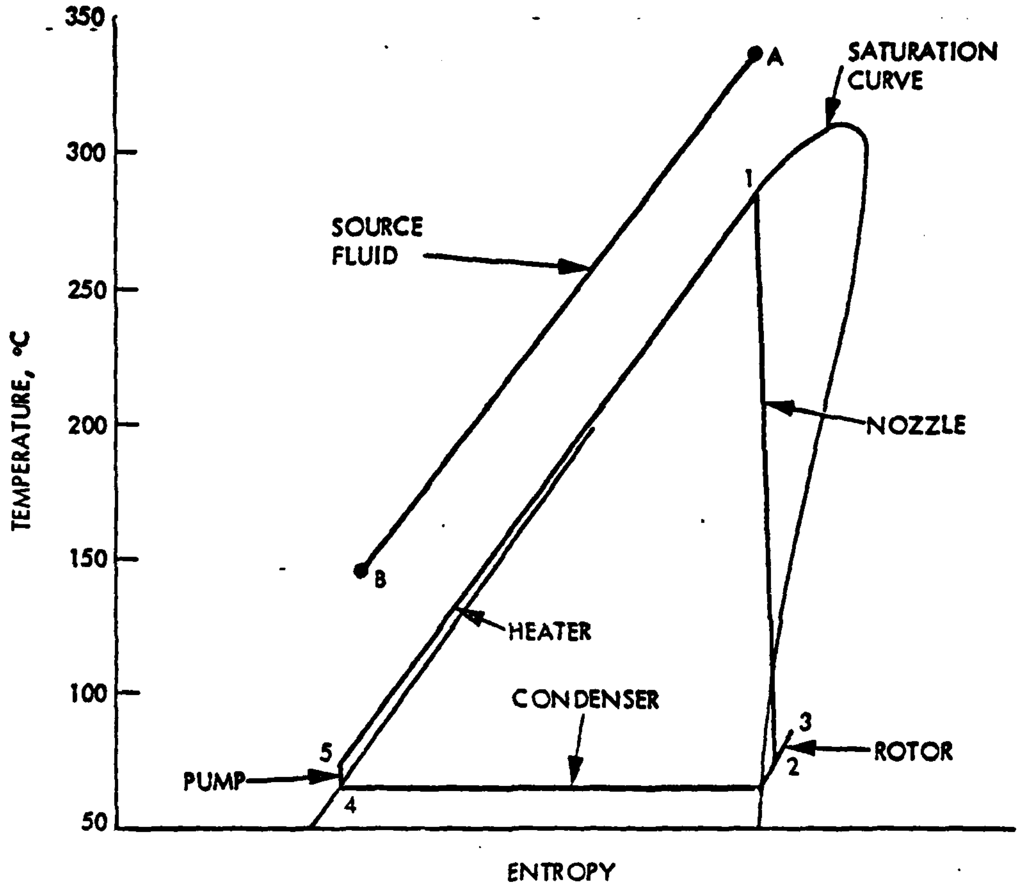


Figure 8. Wet-to-Dry T-S Diagram

in a small turbine engine. For example a steam turbine of 150-kw shaft horsepower using the temperature given in Figure 2 would have a speed of about 60,000 rpm. A comparable two-phase turbine would operate at approximately 10,000 rpm. There is also an efficiency advantage. At temperature corresponding to Figure 2, a steam Rankine cycle would have an efficiency of approximately 28% where-as the two-phase cycle would have an efficiency of 37%. This is assuming equal turbine efficiencies. The two-phase cycle also allows for control of turbine speed because the vapor/liquid mixture ratio can be varied to change the nozzle exit velocity. This is a capability unavailable in a conventional steam turbine.

Both of the dual-phase concepts can be thought of as a form of a regenerated Rankine cycle. The dual-phase cycle by control of liquid/vapor mixture ratio enhances the overall power system controlability. The T-S relationship for a dual-phase two-component engine cycle compared to a Rankine cycle is shown in Figure 9.

Two design studies References 1 and 2, have shown potential advantages in the two-phase engine cycle as compared to the conventional Rankine cycle for marine propulsion. The following advantages were noted:

1. High Efficiency - Full load output power performance gains ranging from 20 to 50 percent was found.

2. Direct Drive - Direct drive at speeds ranging from 90-4500 rpm was found possible with a single-stage turbine.

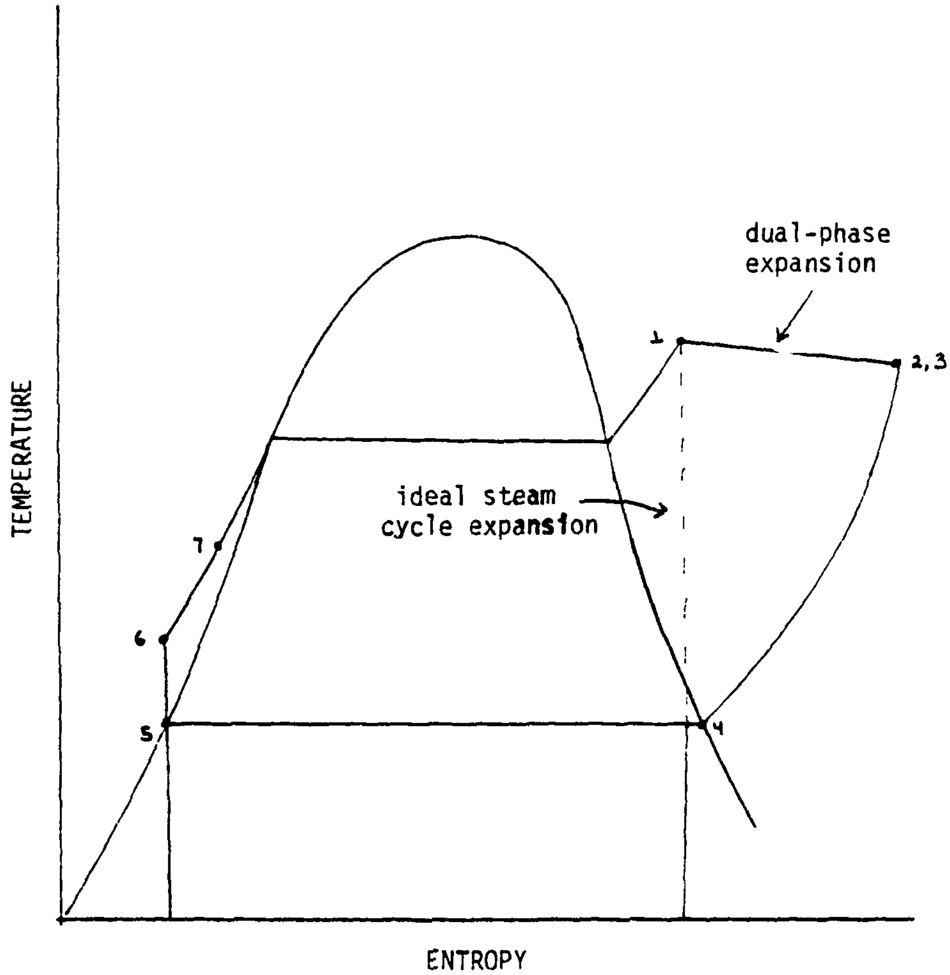


Figure 3. T-S Comparison of Dual-Phase Two-Component Cycle & Rankine Cycle

3. Reduced Volume - Volume reduction of 30 percent were estimated.

4. High Part-Load Efficiency - Variable mass ratio enabled part-load (cruise) efficiency gain of as much as 100 percent.

II. DUAL-PHASE NOZZLE THEORY

The flow phenomenon of a two-phase mixture has been analyzed in Reference 1. It is repeated as follows. The problem is illustrated in Figure 10. A spatially uniform two-component mixture of liquid drops and gas enters a nozzle at high pressure and low velocity and expands to low pressure and high velocity. The objective of the analysis is to determine, for a specified pressure the drop diameter D and the temperatures T_g and T_L, velocities V_g and V_L and flow rates $\dot{m}_g$ and $\dot{m}_L$ of the gas and liquid phases, respectively, at each station in the nozzle given the initial values of D, T_g, T_L, V_g, V_L, the total flow rate, and the properties of the fluids.

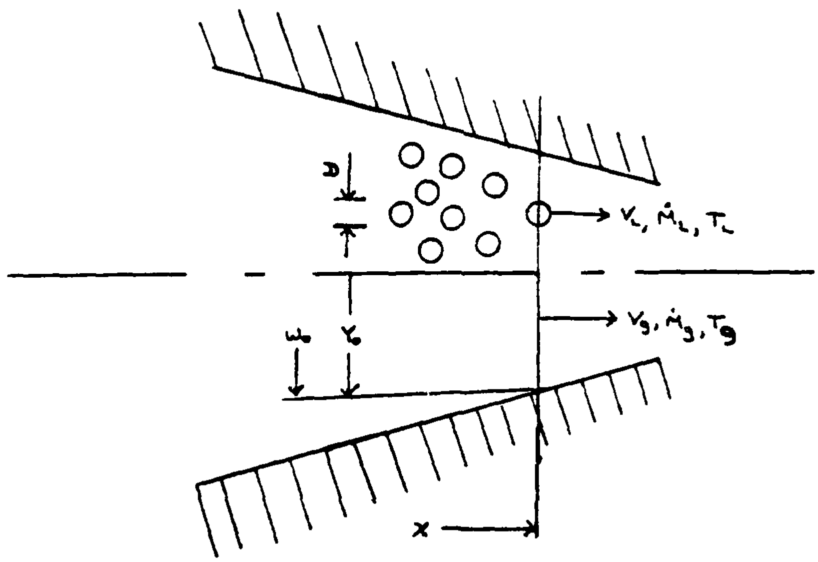


Figure 10. Dual-Phase Nozzle Flow Geometry & Nomenclature

The five relations employed to compute the five unknowns D, T_g, T_L, V_g, and V_L, are (1) the momentum equation for the mixture, (2) the energy equation for the mixture, (3) the drop drag equation, (4) the drop heat transfer equation, and (5) the drop breakup criterion. Solubility and vapor pressure relations provide the flow rate ratio $\dot{m}_g/\dot{m}_L$.

A. ASSUMPTIONS

The assumptions employed in the two-component analysis are as follows:

1. The liquid is uniformly dispersed as spherical drops all of the same diameter.
2. The drops break up to limit the Weber number to 6.
3. There are no external forces acting on the two-phase mixture other than pressure and wall shear, and there is no heat transfer to or from the mixture.
4. The flow is one-dimensional.
5. The drops are large enough for the surface curvature to have negligible effect on the vapor pressure of the liquid and for the surface energy to be negligible.
6. The drops are isothermal.
7. The gas mixture obeys the additive-pressure law.
8. The partial pressure of the predominantly liquid component in the liquid is given by Raoult's Law.
9. The concentration of the predominantly gaseous component in the liquid is given by Henry's Law.

10. The volume of the liquid solution is equal to the sum of the volumes of the pure liquids.

Assumption 1 restricts the analysis to nozzles having spatially uniform injection of the liquid into the gas and operating at gas-to-liquid volume ratios greater than unity. Assumption 2, the drop breakup criterion, states that drop diameter is limited to a value D for which $W_e = \rho_g V_g^2 D/2 = 6$. Thus

$$D_{max} = \frac{12\sigma}{\rho_g V_s^2} \tag{1}$$

where ρ_g is the gas density, V_s is the slip velocity $V_g - V_L$, and is the liquid surface tension. The form of Eq. (1) is physically reasonable in that the Weber number is proportional to the ratio of stagnation pressure $\rho_g V^2{}_s/2$ to surface tension pressure $4\nabla/D$. Hence, a drop would be expected to flatten and breakup at a sufficiently high value of W_e. This has been verified experimentally and the critical Weber number found to be 6, within a factor of about two. An additional restriction is that for actual breakup to occur, the time spent at a Weber number exceeding 6 must be longer than the natural period of oscillation of the drop, $\pi(\rho_L D^3/ \quad)^{1/2}/4$, where ρ_L is the density of the liquid. This requirement is met only in two-phase nozzles longer than about 10 in. and Assumption 2 may cause the analysis to overestimate the exit velocity by increasing amounts as the nozzle length decreases below 10 in.

Assumption 3 excludes magnetohydrodynamic and mechanical body forces. The exclusion of wall heat transfer is correct for the insulated nozzles of interest for power systems. In addition, the relatively high velocity results in short residence lines in the nozzle proper.

Assumption 4 is closely met in practical nozzles since good performance requires small wall angles, large throat radius of curvature, and uniformly distributed injection of the fluids at the nozzle entrance.

Assumption 5 is valid for the drop sizes of 0.001 to 0.010 in. produced by the Eq. (1) breakup criterion. Assumption 6 is valid because of the rapid internal circulation in drops. Assumption 7 introduces negligible error in most cases of practical interest since the vapor pressure of the liquid is small and needs only to be evaluated approximately.

Assumptions 8, 9, and 10 are either valid, or cause little error, for fluids of low miscibility, which are the fluids of interest.

B. DERIVATION OF EQUATIONS FOR FREE-STREAM FLOW

1. Continuity

Referring to Figure 1, the nozzle flow area A is equal to the gas flow area $\dot{m}_g/\rho_g V_g$ plus the liquid flow area $\dot{m}_L/\rho_L V_L$. Thus

$$A = \dot{m}_g\left(\frac{1}{\rho_g V_g} + \frac{r}{\rho_l V_l}\right) \qquad (2)$$

where r is the mass mixture ratio $\dot{m}_L/\dot{m}_g$.

2. Momentum

By Assumption 3, the only force acting on the free-stream flow is that due to the pressure gradient. If $\dot{M}$ is the momentum flux at flow area A, the change in momentum flux across pressure increment dp is

$$d\dot{M} = -A\,dp \tag{3}$$

The momentum flux can be written as the sum of the momentum fluxes of the gas and liquid. Thus,

$$\dot{M} = \dot{m}_g V_g + \dot{m}_l V_l \tag{4}$$

If the flow were allowed to continue at constant pressure, V_g and V_L would become equal to each other at the mass-weighted mean velocity $\overline{V}$. Since for this process, $d\dot{M} = 0$, the value of $\overline{V}$ is given by

$$(\dot{m}_g + \dot{m}_l)\overline{V} = \dot{m}_g V_g + \dot{m}_l V_l \tag{5}$$

or

$$\overline{V} = \frac{V_g + rV_l}{1 + r} \tag{6}$$

Thus, the momentum flux can be written

$$\dot{M} = (\dot{m}_g + \dot{m}_l)\overline{V} \tag{7}$$

Since $\dot{m}_g + \dot{m}_L$ is constant, the change in momentum flux is

$$d\dot{M} = (\dot{m}_g + \dot{m}_l)d\overline{V} \tag{8}$$

Substituting Eqs. (8) and (2) into Eq. (3), $d\overline{V}$ can be written

$$d\overline{V} = -\frac{1}{1 + r}\left(\frac{1}{\rho_g V_g} + \frac{r}{\rho_l V_l}\right) dp \tag{9}$$

The slip ratio is defined as

$$s = V_s/\bar{V} = (V_g - V_l)/\bar{V} \tag{10}$$

This equation can be combined with Eq. (6) to give V_g and V_L in terms of $\bar{V}$:

$$V_g = \left(1 + \frac{rs}{1+r}\right)\bar{V} = a\bar{V} \tag{11}$$

$$V_l = \left(1 - \frac{s}{1+r}\right)\bar{V} = b\bar{V} \tag{12}$$

The gas density can be expressed as

$$\rho_g = W_g p/RT_g \tag{13}$$

where W_g is the effective molecular weight of the gas mixture and R is the universal gas constant. Eq. (13) is the definition of the effective molecular weight W_g, which is the quantity that gives the actual gas density when substituted in Eq. (13).

Substituting Eqs. (11) - (13) into Eq. (8), the differential momentum equation is

$$2\bar{V}d\bar{V} = d\bar{V}^2 = -\frac{2}{1+r}\left(\frac{RT_g}{aW_g p} + \frac{r}{b\rho_l}\right) dp \tag{14}$$

The quantities a and b are slowly varying because s is typically only 0.1 to 0.3 and slowly varying. The quantities r, T_g, W_g and ρ_L are also slowly varying. Integrating

Eq. (14) over a pressure increment Δp, for which a, b, r, T_g, W_g, and ρ_L are constant to within the desired accuracy, the change in $\bar{V}^2$ is

$$\Delta\bar{V}^2 = -\frac{2}{1+r_m}\left(\frac{RT_{g_m}}{a_m W_{g_m}}\log_e\frac{p+\Delta p/2}{p-\Delta p/2} + \frac{r_m \Delta p}{b_m \rho_{l_m}}\right) \tag{15}$$

All quantities other than pressure can be taken outside the integral and evaluated at their mean values (denoted by sub script m) corresponding to the mid-interval pressure p. Thus,

$$\Delta\bar{V}^2 = -\frac{2}{1+r_m} \times \left(\frac{RT_{g_m}}{a_m W_{g_m}}\int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}}\frac{dp}{p} + \frac{r_m}{b_m \rho_{l_m}}\int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}} dp\right) \tag{16}$$

(16)

Performing the integrations,

$$\Delta\bar{V}^2 = -\int_{p-\frac{\Delta p}{2}}^{p+\frac{\Delta p}{2}}\frac{2}{1+r}\left(\frac{RT_g}{aW_g p} + \frac{r}{b\rho_l}\right)dp \tag{17}$$

Equation (17) is the final form of the momentum equation.

3. Energy

The enthalpy change of the mixture between state 1 (the beginning of pressure interval Δp) and state 2 (the end

of the interval) can be evaluated in two steps: (1) phase change at ρ_1, T_{g_1}, T_{L_1} and (2) change to ρ_2, T_{g2}, T_{L2}, at fixed composition.

The enthalpy change for step 1 is

ΔH_1	=	amount of A vaporized	X	enthalpy required to vaporize and heat unit mass of A from T_L to T_{gL}
	+	amount of B vaporized	X	enthalpy required to vaporize and heat unit mass of B from T_{L_1} to T_{g_1}
	+	amount of A and B	X	kinetic energy required to accelerate unit mass from V_{L_1} to V_{g_1}

or

$$\begin{aligned}\Delta H_1 = {} & (\dot m_{a_{g_2}} - \dot m_{a_{g_1}})\,[L_{a_1} + c_{a_{g_1}}(T_{g_1} - T_{l_1})] \\ & + (\dot m_{b_{g_2}} - \dot m_{b_{g_1}})\,[L_{b_1} + c_{b_{g_1}}(T_{g_1} - T_{l_1})] \\ & + (\dot m_{g_2} - \dot m_{g_1})(V^2_{g_1} - V^2_{l_1})/2\end{aligned} \qquad (18)$$

where L and c are latent heat and specific heat, respectively.

Introducing more compact notation.

$$\begin{aligned}\Delta H_1 = {} & \Delta \dot m_{a_g}(L_{a_1} + c_{a_{g_1}}\delta_1 T) \\ & + \Delta \dot m_{b_g}(L_{b_1} + c_{b_{g_1}}\delta_1 T) + \frac{\Delta \dot m_g \delta_1 V^2}{2}\end{aligned} \qquad (19)$$

The enthalpy change for step 2 is evaluated from the temperature, pressure, and velocity changes, with properties evaluated at mean T and ρ for the interval.

$$\Delta H_2 = \dot{m}_{g_2}\left[c_{g_m}(T_{g_2} - T_{g_1}) + \frac{1}{2}(V_{g_2}^2 - V_{g_1}^2)\right] + \dot{m}_{l_2}\left[c_{l_m}(T_{l_2} - T_{l_1}) + \frac{p_2 - p_1}{\rho_{l_m}} + \frac{1}{2}(V_{l_2}^2 - V_{l_1}^2)\right] \tag{20}$$

$$= \dot{m}_{g_2}\left(c_{g_m}\Delta T_g + \frac{\Delta V_g^2}{2}\right) + \dot{m}_{l_2}\left(c_{l_m}\Delta T_l + \frac{\Delta p}{\rho_{l_m}} + \frac{\Delta V_l^2}{2}\right) \tag{21}$$

By Assumption 3, no work is done by the free-stream flow and no heat is transferred to it. Hence,

$$\Delta H_1 + \Delta H_2 = 0 \tag{22}$$

Substituting Eqs. (19) and (21) into Eq. (22) and solving for ΔT_g gives the energy equation for the mixture:

$$\Delta T_g = -\frac{1}{c_{g_m}}\left[\frac{\Delta V_g^2}{2} + r_2\left(c_{l_m}\Delta T_l + \frac{\Delta p}{\rho_{l_m}} + \frac{\Delta V_l^2}{2}\right) + \frac{\Delta \dot{m}_g \delta_1 V^2}{2\dot{m}_{g_2}} + \frac{\Delta \dot{m}_{e_g}}{\dot{m}_{g_2}}\left(L_{e_1} + c_{e_{g_1}}\delta_1 T\right) + \frac{\Delta \dot{m}_{b_g}}{\dot{m}_{g_2}}\left(L_{b_1} + c_{b_{g_1}}\delta_1 T\right)\right] \tag{23}$$

4. Drag

Although no force other than pressure acts on the free-stream flow as a whole, a drag force exists between

the phases. Hence, a second momentum equation must be witten using as the control volume the boundary between the phases.

The two forces acting on each liquid drop are the buoyancy due to the pressure gradient and the drag due to the relative gas velocity. The sum of these is equal to the mass times the acceleration of the drop. Thus, for a single drop.

dynamic pressure of relative gas flow X drag coefficient X frontal area of drop

− volume of drop X pressure gradient = mass drop drop X acceleration of drop

or

$$\left(\frac{1}{2}\rho_g |V_s| V_s\right) C_D \frac{\pi D^2}{4} - \frac{\pi D^3}{6}\frac{dp}{dx} = \left(\frac{\pi D^3}{6}\rho_l\right)\left(V_l \frac{dV_l}{dx}\right) \qquad (24)$$

The absolute value sign in the first term makes the drag force positive when $V_g > V_L$ and negative when $V_g < V_L$.

Solving Eq. (24) for dV_L,

$$dV_l = \frac{3\rho_g |s| s \bar{V}^2 C_D dx}{4\rho_l V_l D} - \frac{dp}{\rho_l V_l} \qquad (25)$$

Differentiating Eq. (12), dV_L can also be expressed in terms of s, r, and $\overline{V}$. Thus,

$$dV_l = b\,d\overline{V} + \overline{V}\left[\frac{s\,dr}{(1+r)^2} - \frac{ds}{1+r}\right] \tag{26}$$

Solving for ds,

$$ds = \frac{b(1+r)\,d\overline{V}}{\overline{V}} + \frac{s\,dr}{1+r} - \frac{(1+r)\,dV_l}{\overline{V}} \tag{27}$$

Substituting dV_L from Eq. (25), noting that $d\overline{V} = d\overline{V}^2/2\overline{V}$, using Eq. (12), and writing for a finite increment, results in,

$$\begin{aligned}\Delta s = {} & \frac{b_m(1+r_m)\,\Delta\overline{V}^2}{2\overline{V}_m^2} + \frac{(1+r_m)\,\Delta p}{b_m\rho_{l_m}\overline{V}_m^2} + \frac{s_m\Delta r}{1+r_m} \\ & - \frac{3\rho_{s_m}|s_m|\,s_m C_{D_m}(1+r_m)\,\Delta x}{4\,b_m\rho_{l_m}D}\end{aligned} \tag{28}$$

This is the drag equation employed when x is specified as a function of ρ.

Solving Eq. (28) for Δ x yields the required alternative equation:

$$\begin{aligned}\Delta x = \frac{4D}{3\rho_{s_m}|s_m|\,s_m C_{D_m}\overline{V}^2}\Bigg[& \Delta p + \frac{b_m^2\rho_{l_m}\Delta\overline{V}^2}{2} \\ & + \frac{b_m\rho_{l_m}\overline{V}_m^2}{1+r_m}\left(\frac{s_m\Delta r}{1+r_m} - \Delta s\right)\Bigg]\end{aligned} \tag{29}$$

5. Heat Transfer

Although no heat is transferred to the mixture as a whole, heat transfer exists between the phases. Hence, a second energy equation must be written using as the control volume the boundary between the phases.

The work dW done on the liquid is that due to drag by the gas. (Only work done by shear or shaft forces is included in dW when writing the First Law for a control volume). Multiplying Eq. (24) by the number flow rate of drops $\dot{N} = 6\dot{m}_L/\pi D^3\rho_L$, the drag force F_d on that quantity of liquid is

$$F_d = \frac{\dot{N}}{8}\rho_g |V_r| V_r C_D \pi D^2 = \frac{\dot{m}_l}{\rho_l}\frac{dp}{dx} + \dot{m}_l V_l \frac{dV_l}{dx} \tag{30}$$

The work done on the liquid is

$$-dW = F_d dx = \dot{m}_l \left(\frac{dp}{\rho_l} + \frac{dV_l^2}{2}\right) \tag{31}$$

The heat dQ transferred from the liquid is made up of two parts: (1) the convective cooling due to the temperature difference between the liquid and gas and (2) the evaporative cooling due to the latent heat supplied to the liquid vaporized. The convective cooling is

$$-dQ_c = hA_d\dot{N}(T_l - T_g)dt \tag{32}$$

where h is the heat-transfer coefficient, $A_d = \pi D^2$ is the surface area of a drop, and $dt = dx/V_L$ is the time required to traverse dx. Thus,

$$-dQ_c = \frac{6h\dot{m}_l(T_g - T_l)dx}{D\rho_l V_l} \tag{33}$$

The evaporative cooling is

$$-dQ_v = L_a d\dot{m}_{a_g} + L_b d\dot{m}_{b_g} \tag{34}$$

The change is enthalpy of the liquid over the pressure increment dp is

$$dH = \dot{m}_l\left(c_l dT_l + \frac{dp}{\rho_l} + \frac{dV_l^2}{2}\right) \tag{35}$$

Substituting Eqs. (31), (33), (34), and (35) into the steady-flow energy equation dQ - dW = dH, the result is

$$\frac{6h\dot{m}_l\delta T dx}{D\rho_l V_l} - L_a d\dot{m}_{a_g} - L_b d\dot{m}_{b_g} = \dot{m}_l c_l dT_l \tag{36}$$

where $\delta T = T_g - T_L$.

Writing for a finite interval, the final form of the drop heat-transfer equation is

$$\Delta T_l = \frac{1}{c_{l_m}}\left[\frac{6h\delta_m T\Delta x}{D\rho_{l_m} V_{l_m}} - L_{a_m}\frac{\Delta\dot{m}_{a_g}}{\dot{m}_{l_m}} - L_{b_m}\frac{\Delta\dot{m}_{b_g}}{\dot{m}_{l_m}}\right] \tag{37}$$

Equations (1), (17), (23), (23), and (37) are the five equations that must be solved simultaneously to obtain the values of the five dependent variables D, T_g, T_L, V_g, and V_L as a function of the independent variable p. To carry out the solution all quantities in the equations must be expressed in terms of these six variables.

C. WALL SHEAR AND BOUNDARY LAYER

For a two-phase nozzle, the momentum flux of the frictionless nozzle flow is that given by

$$\dot{M} = \dot{m}_t \overline{V}$$

The mean mixture density corresponding to the mean velocity $\overline{V}$ is

$$\rho' = \frac{\dot{m}_t}{A\overline{V}} = \frac{\rho_l}{1 + r_a} \qquad (38)$$

where r_a is the ratio of gas flow area to liquid flow area $\rho_l V_l / r \rho_g V_g$.

From the definition of the momentum thickness, the value of θ at a station where the nozzle wall radius is y_o is given by

$$\dot{M} - \dot{M}_f = 2\pi y_o \theta \frac{\dot{m}_t \overline{V}}{A} = 2\pi y_o \rho' \overline{V}^2 \theta \qquad (39)$$

where $\dot{M}_f$ is the momentum flux of the real flow with friction.

The skin-friction coefficient can be defined using the same quantities as single-phase flow

$$C_f = \frac{2\tau_w}{\rho' \overline{V}^2} \tag{40}$$

where τ_ω is the wall shear. It will be shown that a valid C_f value can be provided.

The boundary-layer momentum equation then becomes

$$d\theta = \frac{C_f}{2} dx - \theta \left[\frac{1 + (\delta^*/\theta)}{\overline{V}} d\overline{V} + \frac{1}{\rho' \overline{V}} d(\rho' \overline{V}) + \frac{1}{R_w} dR_w \right] \tag{41}$$

where δ^* is the displacement thickness, i.e., the distance the wall must be moved outward to give the same flow rate as with frictionless flow.

Assuming a $\frac{1}{7}$ power velocity profile and no density variation, the shape factor δ^*/θ is obtained from

$$\frac{\delta^*}{\theta} = \frac{\int_0^\delta [1 - (y/\delta)^{1/7}]\, dy}{\int_0^\delta (y/\delta)^{1/7} [1 - (y/\delta)^{1/7}]\, dy} = \frac{9}{7}$$

where δ is the velocity thickness of the boundary layer.

Noting that $d\overline{V}$ can be written $d\overline{V}^2/2V$, and that $d(\rho'\overline{V}) = d(m_t/A)$, the finite-difference form of Eq. (41) is

$$\Delta\theta = \frac{C_{f_m}}{2} \Delta x - \theta_m \left(\frac{8}{7\overline{V}_m^2} \Delta \overline{V}^2 - \frac{1}{A_m} \Delta A + \frac{1}{y_{o_m}} \Delta y_o \right)$$

Wall shear in homogeneous two-phase flow has been found to be equal to that which would exist with pure liquid at equal velocity and boundary-layer thickness, multiplied by the wetted wall fraction:

$$\tau_w = \frac{C_{f_l}}{2} \rho_l V_l^2 \frac{A_l}{A} = \frac{C_{f_l} \rho_l V_l^2}{2(1 + r_a)} \tag{42}$$

where C_{f_1} is the skin friction coefficient for liquid at a Reynolds number of

$$R_\delta = \frac{\rho_l V_l \delta}{\mu_l}$$

For a 1/7-power profile, the velocity thickness,

$$\delta = \frac{72}{7} \theta$$

A convenient relation for C_{f_1} as a function of R_δ is the Shultz-Grunow relation which can be written

$$C_{f_l} = \frac{0.208}{(\log_{10} R_\delta + 0.425)^{2.584}}$$

Comparison of Eqs. (40) and (42) shows that C_f can be written

$$C_f = \frac{rb}{1 + r} C_{f_l}$$

Thus, the final form of the boundary-layer momentum equation is

$$\Delta\theta = \frac{r_m b_m}{1 + r_m} \frac{C_{f_l}\Delta x}{2} - \theta_m \left(\frac{8\Delta \bar{V}^2}{7\bar{V}_m^2} - \frac{\Delta A}{A_m} + \frac{\Delta y_o}{y_{o_m}} \right)$$

Let $\overline{V}_\delta$ be the mean velocity of the flow including the boundary layer. Then, from Eq. (39),

$$\dot{m}_t \overline{V}_\delta = \dot{M}_f = \dot{m}_t \overline{V} - 2\pi y_o \rho \overline{V}^2 \theta$$

Hence, employing Eq. (38), the mean exit velocity including the boundary layer is

$$\overline{V}_\delta = \overline{V}\left(1 - \frac{2\pi y_o \theta}{A}\right)$$

By the definition of the displacement thickness, the flow rate is reduced by the throat displacement thickness δ_t^* to

$$\dot{m}_\delta = \dot{m}_t\left(1 - \frac{2\delta_t^*}{y_{o_t}}\right)$$

D. NOZZLE THEORY SUMMARY

The preceding equations form the basis for the mathematical model which is used to predict, based on inlet conditions, the exit velocity, and temperature of the mixture. These equations also form the basis for the model which provides the optimum nozzle shape given a set of inlet conditions. Some additional relationships are, however, required. These are:

1. Phase properties - to establish the mass ratio, mass flow rate ratio of gas to liquid, and the thermal conductivity of the mixture.

2. Liquid drop drag coefficients.

3. The liquid drop heat transfer coefficients.

4. Boundary layer momentum thickness and displacement thickness.

5. Skin friction coefficient.

These five additional relationships are developed in detail in Reference [1].

III. COMPUTER PROGRAM DUAL-PHASE NOZZLE

The computer program employed in this study is based on a program developed by Dr. G. Elliott of the Jet Propulsion Laboratory in Pasadena, California. The program was updated and converted for use on the Naval Postgraduate School computer. The Dual-Phase Two-Component program employs the theory in Section II. The program is written in Fortran computer language and can be compiled using a Watfiv or Fortran IV compiler.

This program has been utilized in dual-phase nozzle analysis and to provide values for comparison with the experimental results. To use the computer program the inlet conditions have to be specified. The flow conditions are: inlet pressure; mass ratio; inlet temperature of the gas and liquid; inlet velocity of the gas and liquid; total mass flow rate; and nozzle exit pressure. Section III B, shows specified details for data input.

There are two options that can be chosen. The first is prescribed pressure-versus-distance option MOP=0. The pressure profile P(X) is selected corresponding to the adopted nozzle contour. If the pressure-versus-distance is used a P(X) input table is required. This profile is developed from the actual measured pressure values in the experiments.

(See Appendix A for sample program.) The second option consist of an optimum nozzle contour option MOP=1. This option is useful only when the liquid drop diameter is constant.

The dual-phase two-component computer program is a structured program with thirteen subroutines controlled by a main program. This arrangement improved the programming process through better organization and programming notation.

The control point of the dual-phase two-component computer program is the "main section." It controls the flow path and operation of all input data, property tables, and calculations. It accomplishes this by calling the thirteen subroutines at the appropriate times, saving wanted data in files, and printing out desired information.

One of the most important subroutines which inputs information is the "INTRP" subroutines. INTRP controls the property table inputs. It reads in four two-dimensional tables and fourteen one-dimensional tables. These inputs are the properties of the gas and liquid phases of both components of the flow in the nozzle. The subroutine writes the values of these tables into a file and retrieves appropriate values from that file. INTRP can also interpolate for values used throughout the entire program.

Input of case data is controlled by subroutine "Sect 1." Identification information and case heading information is read and printed for each instance. Sect 1 also places the pressure vs. distance profile, if specified, in an array.

"Sect 2" through "Sect 6" are the subroutines which calculates the flow data. Sect 2 sets the initial conditions indicated in the input, and begins the iterations. Sect 3 computes initial flow rates of both components; the initial area of the nozzle; slip velocity; mean free stream velocity; and slip friction. Sect 4 computes the changes in flow parameters and new distances. It then begins to calculate new conditions such as flow rate, temperature, velocities, surface tension and mean area. Sect 5 is the binary cut convergence routine and computes mean boundary-layer parameters.

If a problem is diagnosed in any subroutines and "diagno" is called, it will p' .nt all output parameters calculated to that point. It also does the same if there is a convergence problem.

There are two subroutines that output calculated data, subroutine "Write" and subroutine "Output." Subroutine "Write" will send output information to the printer for a hard paper copy. Subroutine "Output" reads and stores the output on a file.

The two-phase two-component program has been written with comment statements in the text of the program. These will allow for a more understandable and, therefore, a more easily modified program. For specific details on the content of these subroutines, see Appendix M.

The dual-phase nozzle program was tested for correct output. Sample data and results were obtained from

Dr. David Elliott, were inputted into the program, and executed. The output was compared to the sample data. The program produced duplicate results.

The program begins by storing fluid property tables and reading in all input data. All nozzle inlet conditions are computed. The program then proceeds half a pressure step at a time. At the middle of each pressure interval, the changes in quantities across the interval are computed using the properties interpolated from the table for that pressure, and for the existing temperature. The change in slip is found if the pressure profile P(X) is specified. At the end of each pressure step, the flow conditions are updated and initial conditions are determined for the next step. The dropsize is reduced at the point when the Weber number exceeds six. The flow conditions are printed if the pressure is one selected for output. The computation continues until the last pressure step has been completed and flow conditions at the smallest flow area encountered are printed as the throat conditions.

A. PROPERTY TABLES

1. Heat capacity of component "A" vapor in BTU/LBM-R is a function of temperature and pressure. The two-dimensional tables are entered row-wise. At least two cards are necessary to specify a row and at least two rows must be entered.

Card 1: (format 6E12.6)

cols.

1-12 temperature (R)

13-24=1.0 if this is the last temp for this table

Card 2: (format 6E12.6)

cols.

1-12 pressure (psi)

13-24 heat capacity (BTU/LBM-R)

25-36 pressure (psi)

37-48 heat capacity (BTU/LBM-R)

49-60 pressure (psi)

61-72 heat capacity (BTU/LBM-R)

The maximum entries of temperature are 35 values. For each value of temperature, the maximum number of entries of pressure and heat capacities are 35 values. Each row of this table will be terminated with the pressure and heat capacity equal to 10^5. These two values are not counted in the maximum of 35 entries/rows allowed.

The program shown in Appendix B can be used to determine the values of heat capacities. The program structures its output in the format needed for the table input. It uses input data obtained from Reference 3. The input data must be placed in a two-dimensional table. This table is used in the program to interpolate the values needed for output. Input data must be formatted as follows:

Card 1-16 (format 10F7.4)

cols.

1-7 temperature (R)

at this temp the following is entered:

8-14 heat capacity at .01 P

15-21 heat capacity at .4 Pa

22-28 heat capacity at .7 Pa

29-35 heat capacity at 1.0 Pa

34-42 heat capacity at 4.0 Pa

43-49 heat capacity at 7.0 Pa

50-56 heat capacity at 10.0 Pa

57-63 heat capacity at 40.0 Pa

64-70 heat capacity at 70.0 Pa

The temperature must be entered with increasing value.

2. Heat capacity of component "B" gas, BTU/LBM-R is a function of temperature and pressure. This two-dimensional table has the same format as part A1 above.

3. Molecular weight of component "A" vapor is a function of temperature and pressure. The two-dimensional tables are entered row-wise. At least two cards are necessary to specify a row and at least two rows must be entered.

Card 1: (format 6E12.6)

cols.

1-12 temperature (R)

13-24=1.0 if this is the last temp for this table

Card 2: (format 6E12.6)

cols.

1-12 pressure (psi)

13-24 molecular weight

25-36 pressure (psi)

37-48 molecular weight

49-60 pressure (psi)

61-72 molecular weight

The maximum number entries of temperature are 35 values. For each value of temperature, the maximum entries of pressure and molecular weight are 35 values. Each row of this table will be terminated with the pressure and molecular weight equal to 10^5. These two values are not counted in the maximum of 35 entries/rows allowed.

The program shown in Appendix C can be used to determine the values of molecular weight. The program formats its output in the format needed for the table input of the two-component two-phase computer program. It uses input data obtained from Reference 3. The input data must be placed in a two-dimensional table. This table is used in the program to interpolate the values needed for output. The program used in Figure 8 can only be used with ideal gases. Input data must be formatted as follows:

Card 1-16 (format 10F7.4)

cols.

1-7 temperature (R)

at this temp the following is entered:

8-14 density at .01 P

15-21 density at .4 Pa

22-28 density at .7 Pa

29-35 density at 1.0 Pa

34-42 density at 4.0 Pa

43-49 density at 7.0 Pa

50-56 density at 10.1 Pa

57-63 density at 40.0 Pa

64-70 density at 70.0 Pa

The temperatures must be entered with increasing value.

4. Molecular weight of component "B" gas is a function of temperature and pressure. This two-dimensional table has the same format as part A3 above.

5. There are fourteen one-dimensional tables. The one-dimensional tables are entered in the following format (for Z(T)):

Card 1: (format 6E12.6)

cols.

1-12 Ti-2, oR

13-24 Ti-2

25-36 Ti-1 $2 \le i \le 50$

37-48 Zi-01

49-60 Ti

61-72 Zi and Tj-1 < Tj for $2 \le j \le 50$

Each table is terminated by two consecutive entries of 10^5, i.e., $Tk \equiv Zk \equiv 10^5$ (1.0E5 right adjusted in the field). The fourteen one-dimensional tables are (in order requested):

1. CAL(T) heat capacity of component A liquid, BTU/LBM oR
2. CBL(T) heat capacity of component B liquid, BTU/LBM oR
3. LA(T) latent heat of vaporization for component A, BTU/LBM
4. LB(T) latent heat of vaporization for component B, BTU/LBM
5. PBO(T) vapor pressure of component B
6. ROAL(T) density of liquid component A, LBM/FT3
7. ROBL(T) density of liquid component B, LBM/FT3
8. KAG(T) thermal conductivity of component A gas, BTU/FT HR oR
9. KBG(T) thermal conductivity of component B gas, BTU/FT HR oR

10. VIAL(T) viscosity of liquid component A, LBM/FT HR

11. VIBL(T) viscosity of liquid component B, LBM/FT HR

12. VIAG(T) viscosity of gas component A, LBM/FT HR

13. VIBG(T) viscosity of gas component B, LBM/FT HR

14. SIG(T) surface tension of liquid component B, DYNE/CM

Appendix D gives sample property table for input.

B. CASE INPUT

A blank card must separate the property table from the data set decks following.

Card 1: (format 4A4, A2, 3A4, 7A4, A32, 2I6)

cols.

1-18 date

19-30 case number, may be any alphanumeric data

31-60 identification

61-66 NS, number of pressure steps per printout (right justified integer).* Use -1 if new property tables follows.

67-72 NP, number of printouts (right justified)

Card 2: (All integers right justified in field)

(format 11I6)

cols.

1-6 MBU, =0 constant droplet size, =1 drop breakup

7-12 MOP, =0 X(P) table to be supplied, =1 X(P) is to be optimized

13-18 MGEO, =0 circular, =1 annular

19-24 NDS, maximum number of S iterations

25-30 NSO, maximum number of So iterations

31-36 NB, maximum number of TB iterations

37-42 NNS, first setting of step counter

Card 3: (format 5E12.6)

cols.

1-12 DP, pressure step size, negative for decreasing, psi

13-24 RC, mass flow ratio

25-36 PHI, angle of annular nozzle axis, deg

37-48 RAXO, annular nozzle axis, in.

49-60 EMT, total flow rate *P final = PO + (NS*NP-NNS-1)*DP+DP1

Card 4: (format 6E12.6)

cols.

1-12 H, inverse Henry's Law constant, psi

13-24 ALAM, Lagrangian multiplier

25-26 DPL, first pressure step size

37-48 WAL, molecular weight of liquid a

49-60 WBL, molecular weight of liquid b

61-72 SA, Sutherland constant for component A, oR

Card 5: (format 6E12.6)

cols.

1-12 SB, Sutherland constant for component B, oR

13-24 DO, initial drop diameter, in.

25-36 PO, initial pressure, psia

37-48 TGO, initial gas temperature, oR

49-60 TLO, initial liquid tempeature, oR

61-72 VGO, initial gas velocity, FT/S

Card 6: (format 6E12.6)

cols.

1-12 VLO, Initial liquid velocity, FT/S

13-24 THOO, initial momentum thickness of outer wall boundary layer, in.

25-36 THIO, initial momentum thickness of inner wall boundary layer, in.

37-48 EDS, convergence criterion for S

49-60 ESO, convergence criterion for So

61-72 EB, convergence criterion for T, oR

If MOP=0, the following cards are present: in 10 Card 7: (format 7A4, A2) cols.

1-30 X(P) table identification (and alphanumeric data).

Card 8: (format 6E12.6)

cols.

1-12 pressure, p_{i-2}, psia

13-24 distance, x_{i-2}, in.

25-36 pressure, p_{i-1} $\quad 3 \leq i \leq 75$

37-48 distance, x_{i-1}

49-60 pressure, p_i

61-72 distance, x_i

The last two entries are 1.0E5 and 1.0E5 right adjusted in their fields. The table must be monotonic increasing or decreasing. New property tables may be used by putting -1 in cols. 61-66 of Card 1, and following this with new property tables and data sets. Appendix E is a sample input data.

C. OUTPUT

For each case, the case identification is printed followed by the input parameters. If MOP=0, the X(P) table forms a part of this output. The following output then appears.

1. X distance, in.
2. P pressure, psia
3. R mass flow ratio
4. vb mean free-stream velocity, ft/s
5. a flow area, $in.^2$

6. tb gas temperature, or

7. tl liquid temperature, or

8. vg gas velocity, ft/s

9. vl liquid velocity, ft/s

10. vs slip velocity vg-vl, ft/s

11. s slip fraction vs/vb

12. d drop diameter, in.

13. rv ratio of gas volume flow to liquid volume flow

14. ra ratio of gas flow area to liquid flow area

15. alpha mass fraction of component a dissolved in liquid

16. beta mass fraction of component b vapor in gas

17. mg gas flow rate, lbm/s

18. ml liquid flow rate, lbm/s

19. rog gas density, lbm/ft3

20. rol liquid density, lbm/ft3

21. wag molecular weight of component a gas

22. wbg molecular weight of component b gas

23. wg mean molecular weight of gas

24. pa partial pressure of component a, psia

25. pb partial pressure of component b, psia

26. la latent heat of vaporization of component a, btu/lbm

27. lb latent heat of vaporization of component b, btu/lbm

28. sigma liquid surface tension, dyne/cm

29. cgm specific heat of gas (at midpoint of pressure step), btu/lbm of

30. clm specific heat of liquid, btu/lbm of

31. vigm viscosity of liquid, lbm/ft hr

32. vilm viscosity of gas, lbm/ft hr

33. kgm thermal conductivity of gas, btu/hr ft of

34. rem reynolds number of flow over drops

35. cdm drag coefficient of drops

36. hm heat transfer coefficient of drops, btu/hr ft2

37. rb mass flow ratio after velocity and temperature equalization

38. ab flow area after equalization, in. 2

39. tb temperature after equalization, or

40. rvb volume flow ratio after equalization

41. alphb alpha after equalization

42. betab beta after equalization

43. mgb gas flow rate after equalization, lbm/s

44. mlb liquid flow rate after equalization, lbm/s

45. vilb liquid viscosity after equalization, lbm/ft hr

46. rogb gas density after equalization, lbm/ft3

47. rolb liquid density after equalization, lbm/ft3

48. wagb molecular weight of component a gas after equalization

49.	wbgb	molecular weight of component b gas after equalization
50.	wgb	mean molecular weight of gas after equalization
51.	pab	partial pressure of component a gas after equalization, psia
52.	pbb	partial pressure of component b gas after equalization, psia
53.	g	separator friction parameter
54.	ref	separator film reynolds number
55.	yo	distance from nozzle axis to outer wall, in.
56.	wom	angle of outer wall relative to axis, deg
57.	tho	momentum thickness of outer boundary layer, in.
58.	delo	velocity thickness of outer boundary layer, in.
59.	delso	displacement thickness of outer boundary layer, in.
60.	redom	reynolds number of outer boundary layer
61.	cfom	skin friction coefficient of outer boundary layer
62.	twom	shear stress on outer wall, psi
63.	vbd	mean velocity including boundary layer, ft/s
64.	wim	angle of inner wall relative to axis, deg
65.	thi	momentum thickness of inner boundary layer, in.
66.	deli	velocity thickness of inner boundary layer, in.
67.	delsi	displacement thickness of inner boundary layer, in.

68. redim reynolds number of inner boundary layer

69. cfim skin friction coefficient of inner boundary layer

70. twin shear stress on inner wall, psi

71. nna number of iterations required to optimize X(P)

72. nis number of iterations required to converge on s or so

73. nib number of iterations required to converge on tb

IV. EXPERIMENTAL SYSTEM

The experimental system can be grouped into three subsystems. These are:

a) nozzle

b) air supply system

c) liquid injection system

Each subsystem is described in the following sections. Figure 11 is an overall system schematic.

A. NOZZLE

The nozzle has a convergent-divergent flow passage. It is 12 inches long with a variable exit area. The exit area can be varied from .45313 square inches to .84375 square inches. The pivot point is located 1 inch above the throat. This causes the throat to vary when the exit is varied. Since the change in the throat is negligible, it will be considered to be constant. It has a throat area of .45 square inches. The inlet area is 1.625 square inches. The throat is located 4 inches from the inlet. The nozzle is constructed by sandwiching two 1/2 inche thick machined aluminum nozzle profile plates between 1/2 inch plexiglas plates (Fig. 12). The aluminum nozzle plates are located at the end of a 30 inch long entry section and are easily adjustable. Figure 13 shows a close up of the aluminum section of the nozzle.

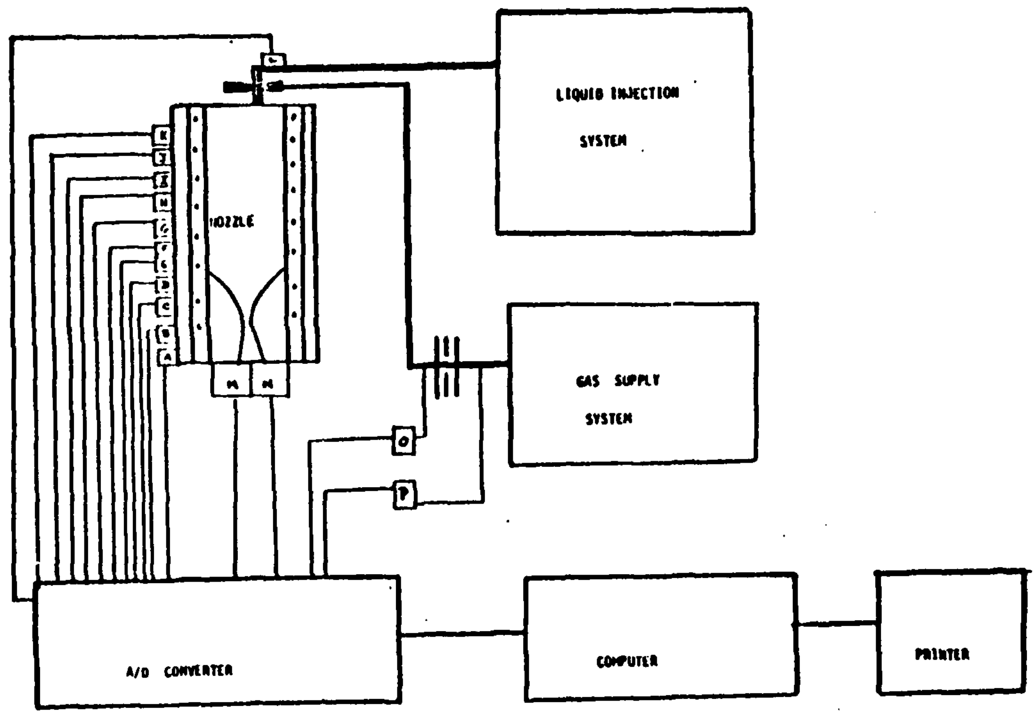


Figure 11. Experimental System Schematic

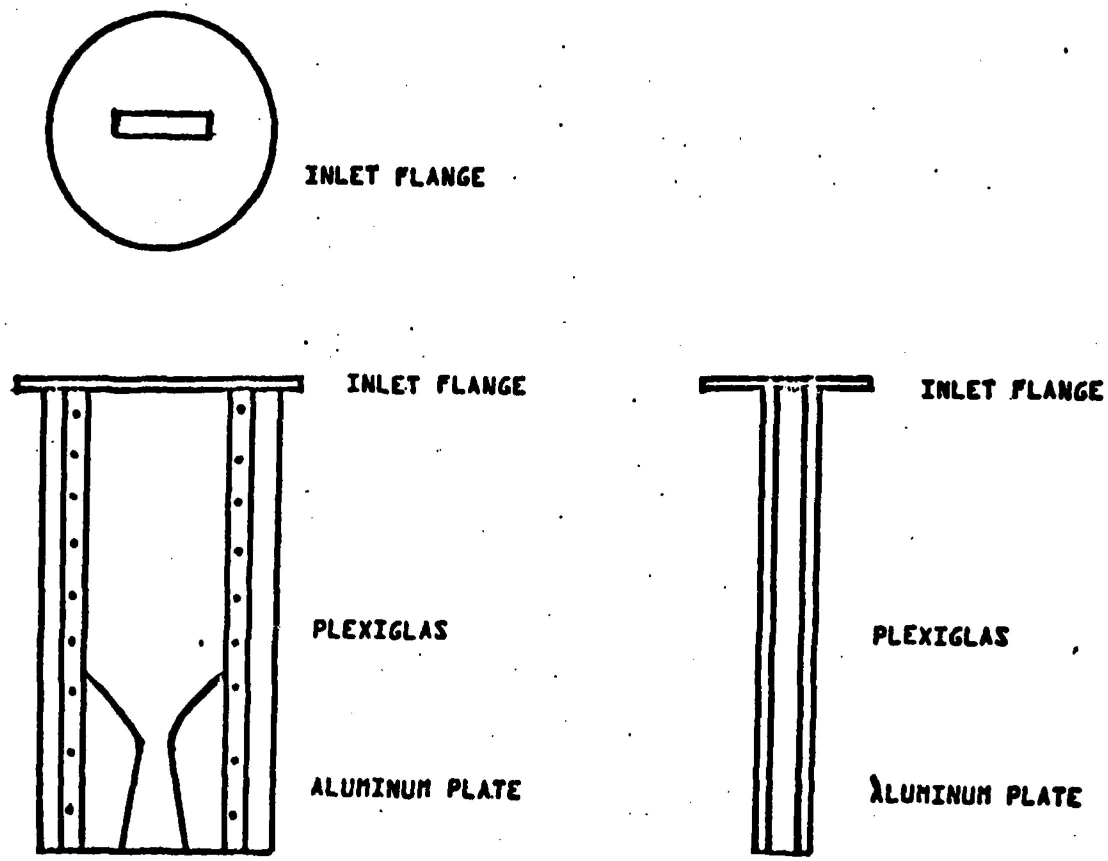


Figure 12. Nozzle Assembly Drawing

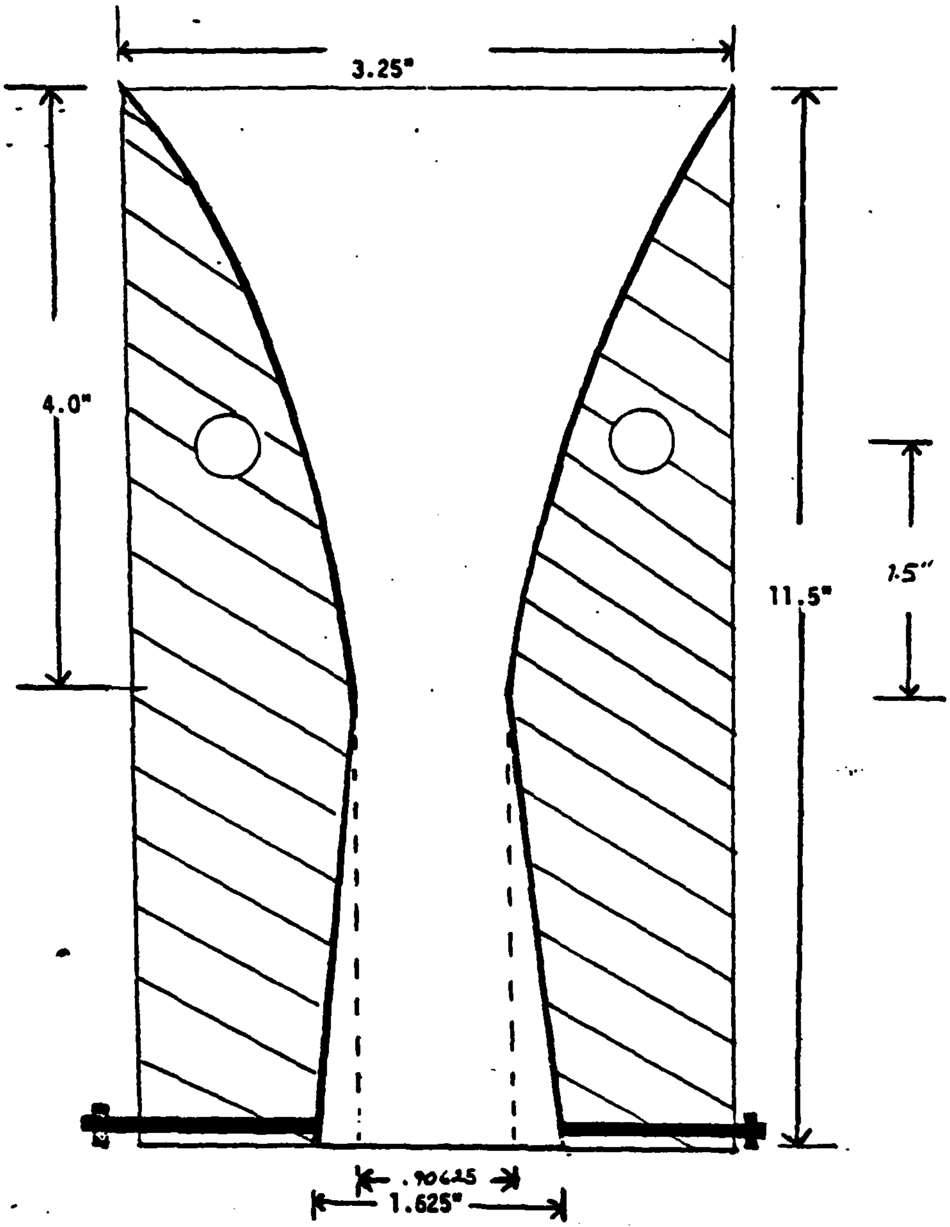


Figure 13. Nozzle Geometry Schematic

The inlet section provides the necessary space for pressure taps, liquid injection tubes, and other instrumentation and configuration options.

B. AIR SYSTEM

The air system is shown in Figure 14. Two 117 cubic feet tanks supplied with compressed air from an Ingersol Rand two-stage air compressor provides the air storage volume required to support the nozzle's operation. Each storage tank has a pneumatically control Norgren gate valve at its exit. These valves are operated by a nitrogen actuator and controlled by a pressure regulator. The nitrogen is regulated to 40 psi control pressure which will open the Norgren valve.

The nozzle is supplied with air via a 3" i.d. pipe. The air supply to the nozzle is controlled by a solenoid actuated nitrogen operated 3 inch ball valve. The nitrogen is supplied via a regulator. By varying the nitrogen supply pressure to the ball valve, supply air pressure to the nozzle can be controlled. Air flow to the nozzle is measured with a standard ASME orifice plate. Figure 15 shows the dimensions of the orifice. The orifice is a model D-10512 with a 0.920 inch bore.

C. LIQUID INJECTION SYSTEM

The liquid injection system, Figure 16, is supplied by house water and is further pressurized by an Aurora electric

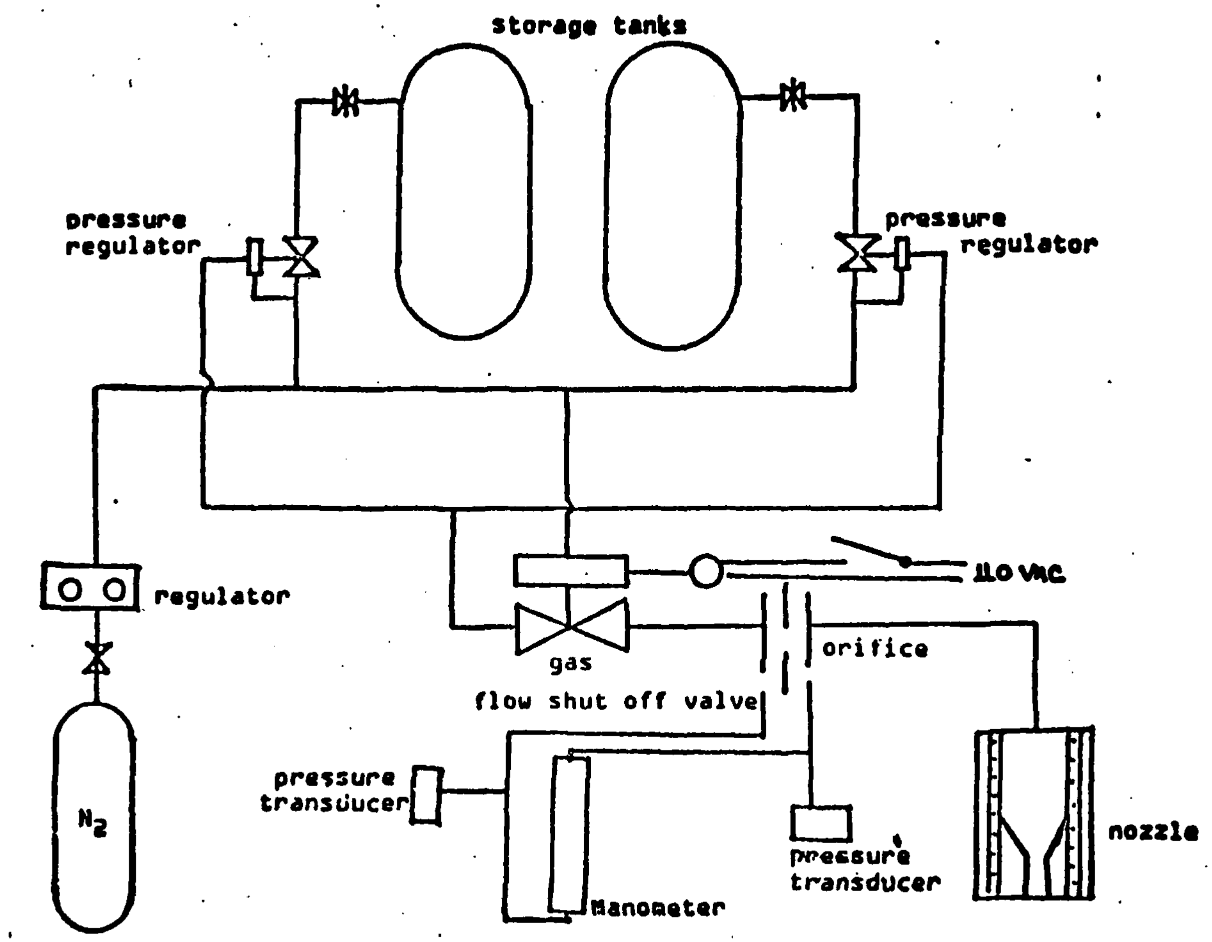


Figure 14. Orifice Schematic

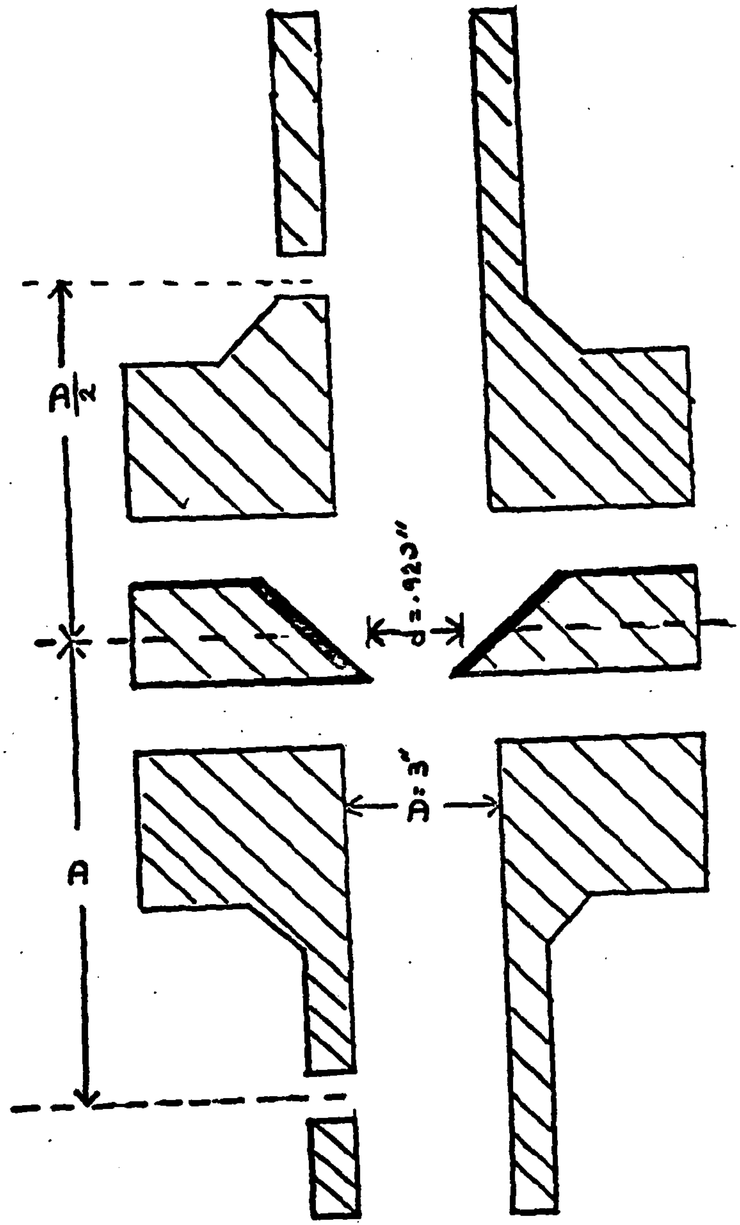


Figure 15. Air System Schematic

pump model/type 317696. The pump is rated at 50 gallons per min. The pump supplies pressurized water to the injection tube via two flowmeters (rotometers). The flowmeters are F&P co. precision bore flowrator tubes. One rotometer is rated at 1 to 12 gallons per min. and the other at .6 gallons per min.

The liquid injector is a 0.25 inch brass tube inserted in the 3" i.d. air supply pipe just upstream of the flange connection to the test section. The injector tube is drilled with sixteen 1/16th inch diameter holes facing the test section entrance. The drilled holes were made as small as possible consistent with achieving a significant liquid mass flow rate.

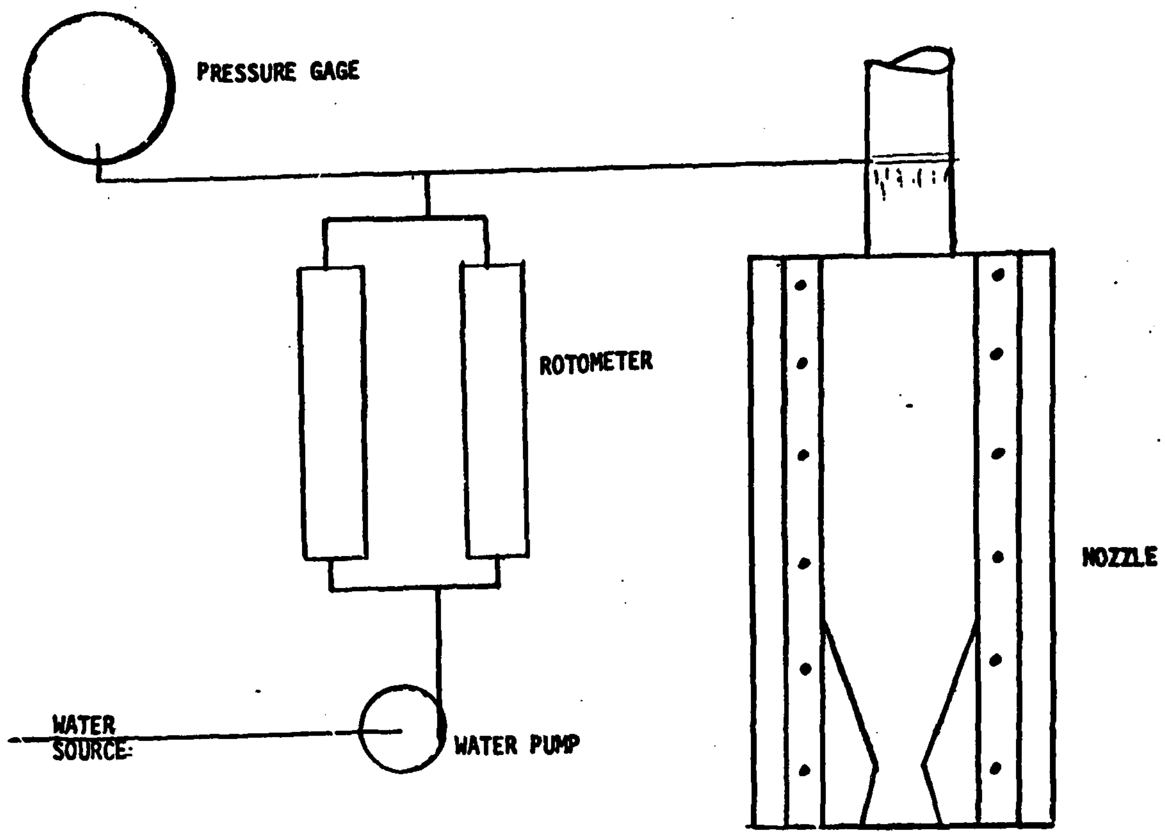


Figure 16. Liquid Injection System Schematic

V. INSTRUMENTATION SYSTEM

The instrumentation system is designed for automated data acquisition, analysis, and display. A schematic is depicted in Figure 17. Where ever possible, test operations and sequencing are under direct computer control. Each parameter measured involves an appropriate transducer, excitation source, and calibration procedure. The major instrumentation subsystems are:

(A) Pressure Measuring Transducers

(B) Nozzle Thrust Force Block

(C) Flow Measurement Devices

(D) Data Acquisition/Control System

A. PRESSURE MEASURING TRANSDUCERS

Pressure measurements are made in fourteen locations throughout the experimental apparatus. Eleven Micro Switch 140PC pressure transducers model PK 87633 are placed on the nozzle assembly to measure pressure at various axial positions. Specifications for this model transducer are shown in Figure 18. The first pressure tap is located at one half inch from the inlet along the axis of the nozzle. The remainder are placed at one inch intervals toward the nozzle exit. These pressure taps are connected to the pressure transducers via a 1/4" o.d. plastic tubing. The

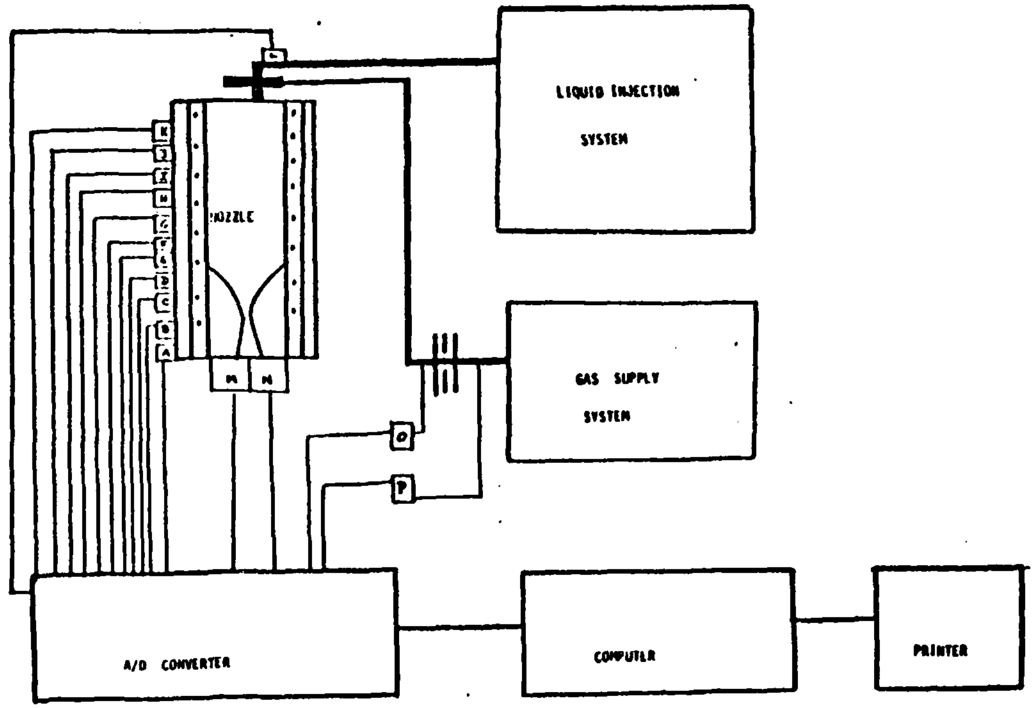
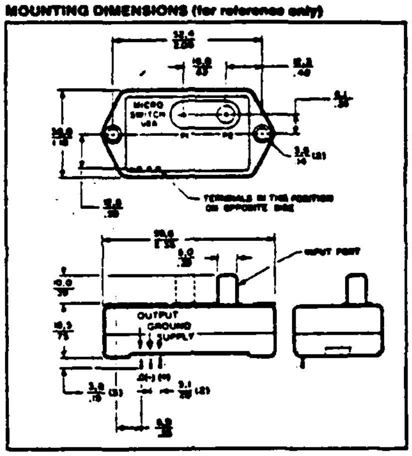


Figure 17. Instrumentation System Schematic

MOUNTING DIMENSIONS (for reference only)

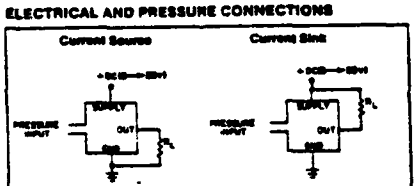


140PC SPECIFICATIONS at 8.0 0.01VDC, 25°C

ALL LISTINGS

PARAMETER	PRESSURE RANGE (psi)	Min.	Typ.	Max.	UNITS
F.S.O. (Full Scale Output)*	All	4.85	5.00	5.15	Volts
Null Offset	All	0.95	1.00	1.05	Volts
Excitation	All	8.00		20.0	VDC
Output Current	All				
Source		10.0			mA
Sink		5.0			
Supply Current	All				
(10K ohm load)			8.0		mA
Overpressure	0-1			20	psi
	0-5			20	
	0-15			45	
	0-15/0-30(L)			60	
Operating Temperature	-55°C to +125°C(-65°F to +257°F)				

ELECTRICAL AND PRESSURE CONNECTIONS



WARNING: Damage may result from reversal of supply and ground connections.

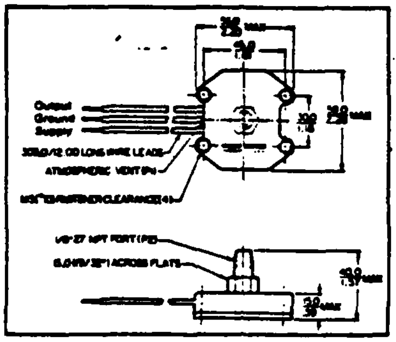
Figure 18. 140PC Pressure Transducer Specifications

pressure transducers are mounted on the side panel of the nozzle. See Figure 19 for locations. Each transducer has an identification letter corresponding to its position. Table I is the ID code for the transducers.

At the nozzle inlet a Micro Switch 200PC pressure transducer model PK 87690 is placed in the inlet line to measure the dual-phase mixture inlet pressure. Specifications for this model transducers are shown in Figure 19. Gas supply pressure is measured using a 200PC pressure transducer located at the orifice outlet. This transducer is also used to help measure differential pressure across the orifice. Another 200PC transducer is placed at the inlet of the orifice. The data acquisition program calculates the orifice differential pressure and then the air mass rate using the output from the above two transducers.

The pressure transducers provide output voltage proportional to applied pressure. These operate from a single, positive supply voltage ranging from 8 to 20 VDC. The supply voltage was maintained at 15VDC.

Each pressure transducer sends back a signal proportional to the input pressure. The signal is converted in the A/D converter to a digital signal which can be read by the HP9826. The pressure transducers were calibrated using a known pressure source. Appendix F depicts a sample calibration program written for a HP9826 computer. This program reads ten



200PC SPECIFICATIONS at 8.0 ± 0.01VDC, 25°C (unless otherwise noted)

PARAMETER	PRESSURE RANGE (psi)	Min.	Typ.	Max.	UNITS
F.S.O. (Full Scale Output)*	All	4.80	5.00	5.20	V
Null Offset	All	0.95	1.00	1.05	V
Proof Pressure ①	0-100			200	psi
	0-250			500	
Burst Pressure ②	0-100		800		psi
	0-250		1000		
Excitation	All	8.0		20.0	VDC
Output Current	All				
Source		10.0			mA
Sink		5.0			
Supply Current	All		8.0		mA
Operating Temperature	All	-55°C to +125°C (-68°F to +257°F)			

*F.S.O. is the algebraic difference between end points (null and full pressure outputs).

① Maximum pressure without damage
② Without housing envelope rupture.

ELECTRICAL AND PRESSURE CONNECTIONS

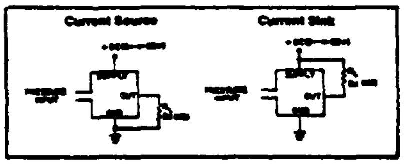


Figure 19. 200PC Pressure Transducer Specifications

Table I. ID Code for Instrumentation

Letter Designation	Description
A	10.5" from inlet
B	9.5" from inlet
C	8.5" from inlet
D	7.5" from inlet
E	6.5" from inlet
F	5.5" from inlet
G	4.5" from inlet
H	3.5" from inlet
I	2.5" from inlet
J	1.5" from inlet
K	0.5" from inlet
L	inlet nozzle pressure
M	force-block signal
N	force-block excitation voltage
O	orifice exit pressure
P	orifice inlet pressure

$$Pressure = A + B(volts) + C(volts)^2 + D(volts)^3$$

pressure transducer	A	B	C	D
A	-6.049	3.926	-.17336	.01121
B	-7.059	4.234	-.22921	.01415
C	-.6491	3.934	-.16025	.00945
D	-7.056	4.692	-.34118	.01898
E	-7.009	4.152	-.20717	.01237
F	-6.389	3.933	-.16055	.00951
G	-6.589	3.956	-.16427	.00961
H	-6.588	3.908	-.15806	.00942
I	-6.595	3.949	-.16270	.00957
J	-6.353	3.927	-.16509	.00998
K	-6.203	3.846	-.14697	.00880
L	-20.207	11.157	-.08591	.00492
O	-20.668	11.068	-.07562	.01118
P	-18.827	11.928	-.17715	.01101

Figure 20. List of Polynomial Coefficients for Pressure Transducer

values of pressure for each 140PC transducer and gives the mean and standard deviation for each from 0 to 45 psi in 5 psi increments. Appendix G depicts sample output of the program for a given pressure. Appendix H illustrates the program used to calibrate the 200PC pressure transducers. The program works as above, except values are taken from 0 to 60 psi at 5 psi increments.

Data obtained during calibration source pressure is plotted for each pressure transducer (Appendix I). Each plot was curve fitted with a third order polynomial. Figure 20 shows coefficients of the polynomial. These polynomials are used in the data acquisition/control program to convert transducer readings to pressure readings.

B. NOZZLE THRUST FORCE-BLOCK

The thrust produced by the nozzle was employed to deduce the nozzle exit velocities. The thrust was measured by instrumenting a target plate in the exit flow field. Appropriate screens were installed to prevent liquid "bounce back." The jet momentum force on the target is acquired by a balance beam system shown in Figure 21. A Kistler-Morse force block provides an analog signal proportional to the nozzle jet momentum.

The calibration of the force-block was completed by placing known weights on the force-block side of the balance

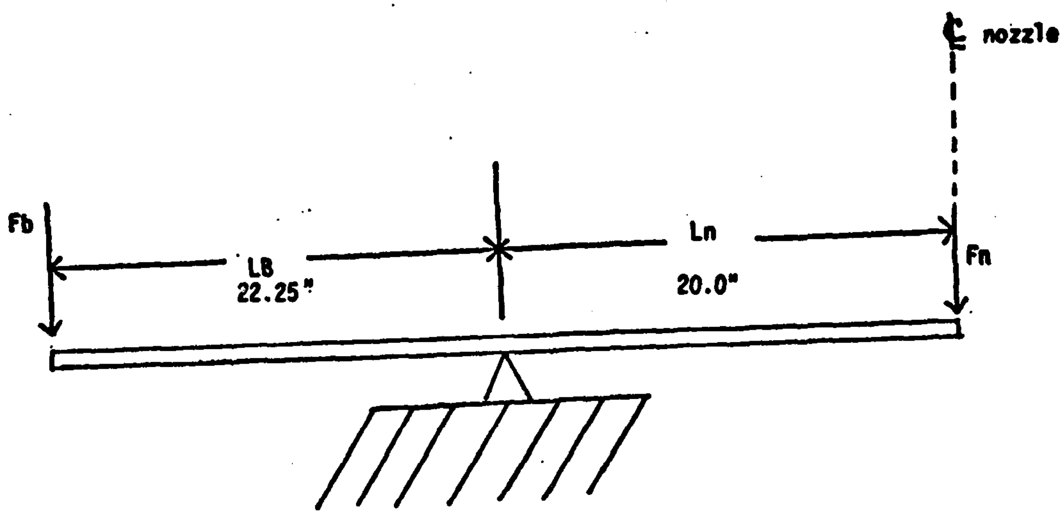


Figure 21. Force-Block Balance Beam Diagram

beam, (Figure 21), and recording the voltage produced. Appendix J shows results of this calibration. These results were curve fitted with a third order polynomial. The following is the volt-to-force conversion polynomial:

FB = (1/453.6)*(-234.396+48715.28*VOLTS-11261.54*VOLTS+33899.3*VOLTS)

FN = FB*LB/LN

FN = FORCE AT NOZZLE EXIT (LBF)

FB = FORCE AT FORCE BLOCK (LBS)

LB = LENGTH FROM PIVOT TO FORCE BLOCK(IN.)

LN = LENGTH FROM PIVOT TO DIRECTIONAL OBSTRUCTION(IN.)

C. FLOW MEASUREMENT

1. Air mass flow measurement for the system achieved by measuring the inlet and outlet pressure on a D-10512 orifice with a 0.92 inch bore. For details on orifice see Section III. Air flow is calculated in the data acquisition program. The program uses the following equation obtained from References 4 and 5.

$$M_{air} = K\, A_2\, Y\sqrt{2G_c \quad \rho_1 (P1-P2)} \qquad \text{where}$$

$K = CE$

$E = 1/(1-\beta^4)^{1/2}$

$\beta = d/D$

$C = 0.60$

A_2 = AREA OF ORIFICE = $\frac{\pi D^2}{4}$ FT2

G_c = 32.2 FT/SEC2

ρ_1 = DENSITY LBM/FT3

P1 = PRESSURE AT INLET IN LBF/FT2

P2 = PRESSURE AT LUTLET IN LBF/FT2

M_{air} = AIR MASS FLOW RATE LBM/SEC

The discharge coefficient C is the factor that accounts for losses through the orifice. Since the values of C varies from .62 to .60 for R_d number from 10^4 to 10^7 with β = .3, C will be considered constant.

2. Water flow measurement was made using two rotometers. Calibration of the rotometers were made by measuring the time for a given weight of fluid flow. The mass flow rate was calculated and plotted versus the rotometer reading. Appendix K is the plot of the results. The plot was curve fitted with a third order polynomial. The following is that polynomial:

$$MH20 = -.0063268+.002097278*RR-.00000658*RR^2+1.1X10*RR^2$$

where RR = rotometer reading

D. DATA ACQUISITION/CONTROL SYSTEM

The heart of the data acquisition system is a HP9826 small computer. The HP9826 communicates via a Hewlett Packard 3497A data acquisition/control system. This system gathers data from the pressure transducers and nozzle thrust force-block. It converts the analog signal to digital data, and stores the data in memory. Figure 22 shows a pressure transducer to A/D converter channel connection, and Figure 23

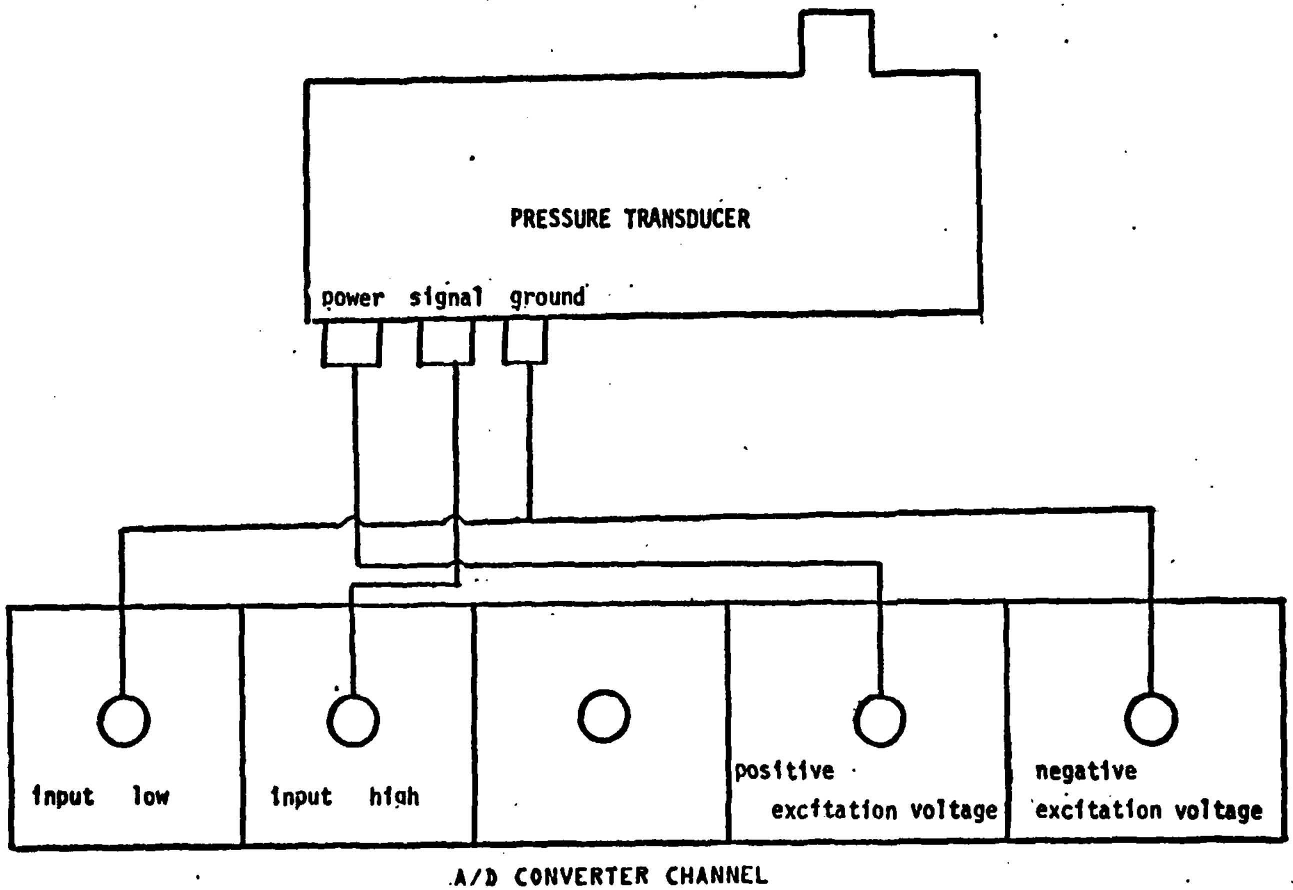


Figure 22. Transducer-to-Channel Connection

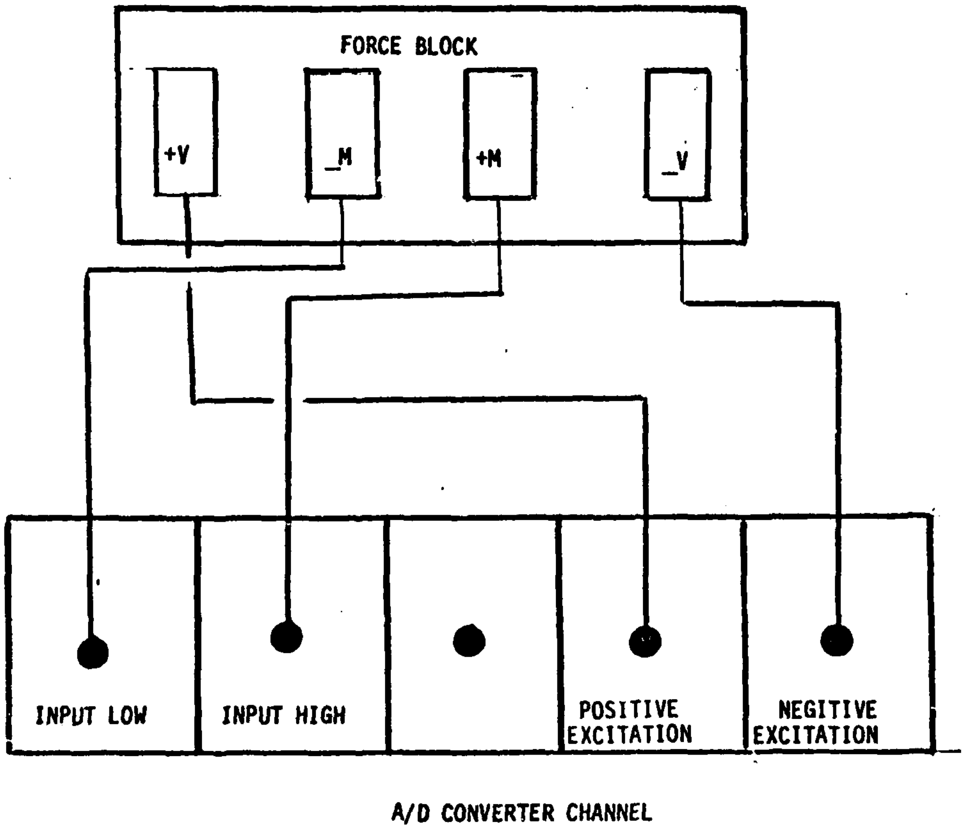


Figure 23. Force-Block-to-Channel Connection

CHANNEL 7	CHANNEL 8	CHANNEL 9	CHANNEL 16	CHANNEL 17	CHANNEL 18
G	H	I		EXCITATION VOLTAGE	
CHANNEL 4	CHANNEL 5	CHANNEL 6	CHANNEL 13	CHANNEL 14	CHANNEL 15
D	E	F	O	P	M,N
CHANNEL 1	CHANNEL 2	CHANNEL 3	CHANNEL 10	CHANNEL 11	CHANNEL 12
A	B	C	J	K	L

BUS CONNECTION TO A/D CONVERTER

Figure 24. Bus Connection-to-A/D Converter Connections

the force-block to A/D converter channel connection. Figure 24 depicts the current connection to the data acquisition/control system bus from the sensors.

The data acquisition and analysis program is a fully automated system which integrates the use of the HP9826, HP3497A, and all sensor devices. The program can be divided into three sections:

1. Data Acquisition - Data is acquired from 15 different sensor devices. All system parameters are initialized and configuration types are inputted into the computer memory for future use. Ten readings are made on each sensor and a mean value for each is calculated and stored in memory.
2. Data Conversion - Input data conversion is completed by using calibration information obtained on each pressure transducer and force-block. The program takes the stored mean values from memory, and converts the input voltage to a pressure or force using the third order calibration polynomial for each sensor.
3. Data Analysis - This is the heart of the program in that all performance parameters are calculated and printed. It uses all of the above information to calculate mass flow rate of water, mass flow rate of air, total mass flow rate, thrust, mixture

ratio, exit velocity and all pressure information. The following equations are also used:

Exit Velocity = (Thrust/Total Mass Flow Rate)* g_c(ft/sec)

Mixture Ratio = $\dot{m}_{water}/\dot{m}_{air}$

Total Mass Flow Rate = $\dot{m}_{water} + \dot{m}_{air}$ $(\frac{lbm}{sec})$

Appendix L is the data acquisition program and sample output.

VI. EXPERIMENTAL RESULTS

Six test runs were made using the equipment described in the previous sections. It was found that the inlet pressure to the nozzle remained nearly constant for each setting. The testing was conducted by maintaining a constant air control valve setting and varying the mass flow rate of water. The regulator outlet pressure of the nitrogen bottle which controls the air valve was set at 30 psi and 15 psi. These settings correspond to nozzle inlet pressure of 35 $\pm$ 1.0 psi and 29 $\pm$ 1.0 psi respectively. For each nozzle inlet pressure, experimental data was obtained at varying mass ratios of water-to-air in the range of 2 to 13. These experiments were conducted with three discharge area ratios (A_{inlet}/A_{out}). Those ratios are: 3.586, 2.600, and 1.9259. The results of the six experimental tests are displayed in Tables II through VII.

Inlet air was limited to a maximum value of 40 psi. The 140PC pressure transducer's maximum output pressure is 40 psi, (see information on 140PC transducer Figure 21). The experimental system has the ability to reach higher pressures. The present configuration may be operated to 70 psig.

Table II. Experimental Data Exit Area = .45313 sq. in.
Inlet Pressure = 29$\pm$1.5psi

NOZZLE GEOMETRY 0.45313 SQ.IN*********PRESSURE 29.00000 PSI

MASS FLOW RATE TOTAL	AIR	WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06050	0.01830	0.04220	2.30000	1998.00000	1950.39900	3.75000
0.10150	0.01840	0.08346	4.62000	1243.30000	1300.00000	3.92000
0.13650	0.01790	0.11860	6.64000	969.69990	1001.89900	4.11000
0.16630	0.01770	0.14860	8.39000	806.10000	830.60000	4.16000
0.19220	0.01770	0.17450	9.83000	719.69990	760.30000	4.24000
0.21490	0.01750	0.19730	11.26000	643.19990	695.50000	4.29000
0.23580	0.01750	0.21810	12.39000	602.50000	642.00000	4.41000
0.25550	0.01760	0.23790	13.51000	550.00000	620.89990	4.37000

Table III. Experimental Data Exit Area = .45313 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY 0.45313 SQ.IN*********PRESSURE 35.00000 PSI

MASS FLOW RATE TOTAL	MASS FLOW RATE AIR	MASS FLOW RATE WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06300	0.02080	0.04220	2.02000	2440.50000	2430.30000	4.77000
0.10410	0.02060	0.08346	4.05000	1536.10000	1611.50000	4.97000
0.13890	0.02030	0.11860	5.85000	1192.19900	1240.69900	5.14000
0.16840	0.01980	0.14860	7.50000	1007.30000	1031.30000	5.27000
0.19450	0.02000	0.17450	8.73000	880.83000	930.80000	5.32000
0.21720	0.01990	0.19730	9.93000	810.60000	860.75000	5.47000
0.23820	0.02000	0.21810	10.89000	735.69990	810.50000	5.44000
0.25750	0.01950	0.23790	12.18900	669.19990	715.30000	5.34000

Table IV. Experimental Data Exit Area = .62500 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY 0.62500 SQ.IN********PRESSURE 29.00000 PSI

MASS FLOW RATE TOTAL	AIR	WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06040	0.01820	0.04220	2.32000	1834.50000	1880.30000	3.44000
0.10150	0.01810	0.08346	4.61000	1158.00000	1201.19900	3.66000
0.13660	0.01800	0.11860	6.59000	937.80000	953.60000	3.98000
0.16650	0.01790	0.14860	8.32000	802.19990	803.10000	4.15000
0.19220	0.01770	0.17450	9.85000	688.60000	749.19990	4.21000
0.21510	0.01780	0.19730	11.10000	643.19990	702.10000	4.30000
0.23550	0.01740	0.21810	12.60000	589.89990	670.10000	4.32000

Table V. Experimental Data Exit Area = .62500 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY 0.62500 SQ.IN********PRESSURE 35.00000 PSI

MASS FLOW RATE TOTAL	MASS FLOW RATE AIR	MASS FLOW RATE WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.09370	0.02900	0.04220	2.02000	2165.89900	2210.30000	4.24000
0.13910	0.02050	0.11860	5.77000	1097.10000	1153.10000	4.74000
0.16900	0.02050	0.14860	7.27000	940.50000	998.39990	4.94000
0.19980	0.02030	0.17450	8.60000	832.89990	885.30000	5.04000
0.21760	0.02030	0.19730	9.72000	765.39990	801.60000	5.17000
0.23820	0.02010	0.21810	10.87000	720.50000	753.39990	5.32000
0.25770	0.01890	0.23790	12.03000	674.80000	700.30000	5.40000

Table VI. Experimental Data Exit Area = .84375 sq. in.
Inlet Pressure = 29±1.5psi

NOZZLE GEOMETRY 0.84375 SQ.IN********PRESSURE 29.00000 PSI

MASS FLOW RATE TOTAL	MASS FLOW RATE AIR	MASS FLOW RATE WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06110	0.01890	0.04220	2.23000	1586.69900	1653.39900	3.01000
0.10210	0.01860	0.08346	4.48000	1069.10000	1101.60000	3.39000
0.13700	0.01840	0.11860	6.44000	850.39990	900.89990	3.61000
0.16680	0.01820	0.14860	8.19000	754.69990	791.10000	3.91000
0.19250	0.01800	0.17450	9.69000	655.60000	720.10000	3.92000
0.21560	0.01820	0.19730	10.84000	596.00000	675.30000	3.99000
0.23610	0.01800	0.21810	12.14000	576.10000	638.19990	4.22000
0.25560	0.01770	0.23790	13.46000	570.50000	610.50000	4.52000

Table VII. Experimental Data Exit Area = .84375 sq. in.
Inlet Pressure = 35±1.5psi

NOZZLE GEOMETRY 0.84375 SQ.IN*********PRESSURE 35.00000 PSI

MASS FLOW RATE TOTAL	AIR	WATER	MASS RATIO	EXPERIMENTAL EXIT VELOCITY	REAL EXIT VELOCITY	THRUST
0.06350	0.02130	0.04220	1.98000	1727.39900	1807.60000	3.40000
0.10440	0.02090	0.08346	3.99000	1081.50000	1102.30000	3.50000
0.13900	0.02040	0.11860	5.82000	891.12980	913.80000	3.85000
0.16890	0.02030	0.14860	7.31000	721.50000	810.39990	3.78000
0.19460	0.02010	0.17450	8.70000	691.89990	741.10000	4.18000
0.21690	0.01960	0.19730	10.10000	604.19990	675.19990	4.07000
0.23810	0.02000	0.21810	10.90000	583.50000	660.00000	4.35000
0.25780	0.01980	0.23790	12.00000	516.96990	654.39990	4.42000

VII. DISCUSSION

The results of this investigation are in two parts; the experimental test results and the computer outputs based on initial conditions similar to those of the experiments.

The key variables are: the nozzle overall area ratio A_R, liquid/air mass flow ratio, nozzle exit velocity, nozzle supply pressure, nozzle thrust, and the nozzle axial pressure profiles. Figures 25 through 34 present the exit velocity vs. mass ratio results for the experiment and computer output. Figure 29-34 illustrates the comparison of the experimental results and the corresponding computer output. Figure 35 illustrates the variation of nozzle thrust with mass ratio for different area ratios and inlet pressures. Figures 36 and 37 present the axial pressure profiles.

In all cases the exit plane velocity decreases as the liquid/air mass ratio is increased. In the low mass ratio range (i.e., less than $\approx$ 5) the velocity decrease is very pronounced. Past a mass ratio value of $\approx$ 10 the velocity of the mixture becomes relatively insensitive to the mixture ratio. This is as would be expected. For the same inlet conditions there is a fixed amount of energy available for conversion to its kinetic form. In the nozzle process the energy is conserved and thus an increasing mass ratio is

manifested in a decreasing exit plane velocity. In all cases the agreement between the experimental tests and the analytic predictions are with in $\simeq$ 10%.

There also was apparent and a consistent trend with respect to the nozzle area ratio and the exit velocity. As the nozzle exit area was increased the exit velocity of the mixture decreased. The effect seems to be more pronounced at the lower mass ratios. This trend was confirmed by observations of the actual flow field in the nozzle. If the exit area was increased significantly (beyond the max area used in those tests) there was evident an abrupt and severe separation within the diverging portion of the nozzle passage. This was accompanied by a drastic decrease in exit velocity as evidenced by the output from the thrust target. It appears that the diverging portion of the nozzle, at a certain point, starts to behave as a subsonic diffuser and hence experiences an adverse pressure gradient. This reasoning is in part confirmed by the pressure profiles identified in Figures 36 and 37.

The relationship between measured thrust and mass ratio (Figure 35) indicates a slightly increasing trend. This may be explained by considering the following. Each set of data points (at constant inlet air pressure and constant nozzle exit area) is developed by varying the mass ratio. This, in turn, is achieved by increasing the liquid rate by increasing the liquid supply pressure. The net result is an

increase in the liquid inlet velocity or an increase in the inlet energy level. Thus a particular data set is not truly at a constant inlet energy level but is increasing.

Perhaps the major discrepancy between the experimental test results and the computer analytic model is evidenced in the axial pressure profiles of Figures 36 and 37. It is clearly evident that at a certain point the nozzle passage reverts from a nozzle to a diffuser. This transition point occurs slightly downstream of the throat and the pressure starts to increase.

Unfortunately the computer analytic model requires a pressure profile as an input. Furthermore the pressure profile must be continuously decreasing. Thus the profile as obtained from the experiment are not directly useable. The situation is examined with the aid of Figure 38. Curve A is a typical axial pressure distribution as obtained from the experiment. Curve B is a pressure distribution used by Elliott in the application of his computer program. Pressure profiles C and D were arbitrarily defined and the exit plane velocity for each was calculated. Velocity variation in the range of 1% is evident. It appears that the final exit velocity is relatively insensitive to the actual pressure profile in the nozzle.

In light of the preceeding difficulty of matching the experimental pressure profile to the computer model and the

AD-A125 730 DUAL-PHASE NOZZLE FLOW(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA T C NOLLIE OCT 82 2/3

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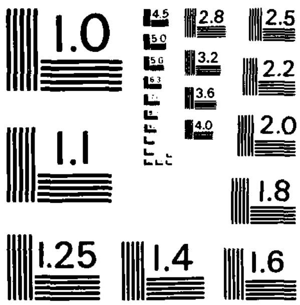

MICROCOPY RESOLUTION TEST CHART
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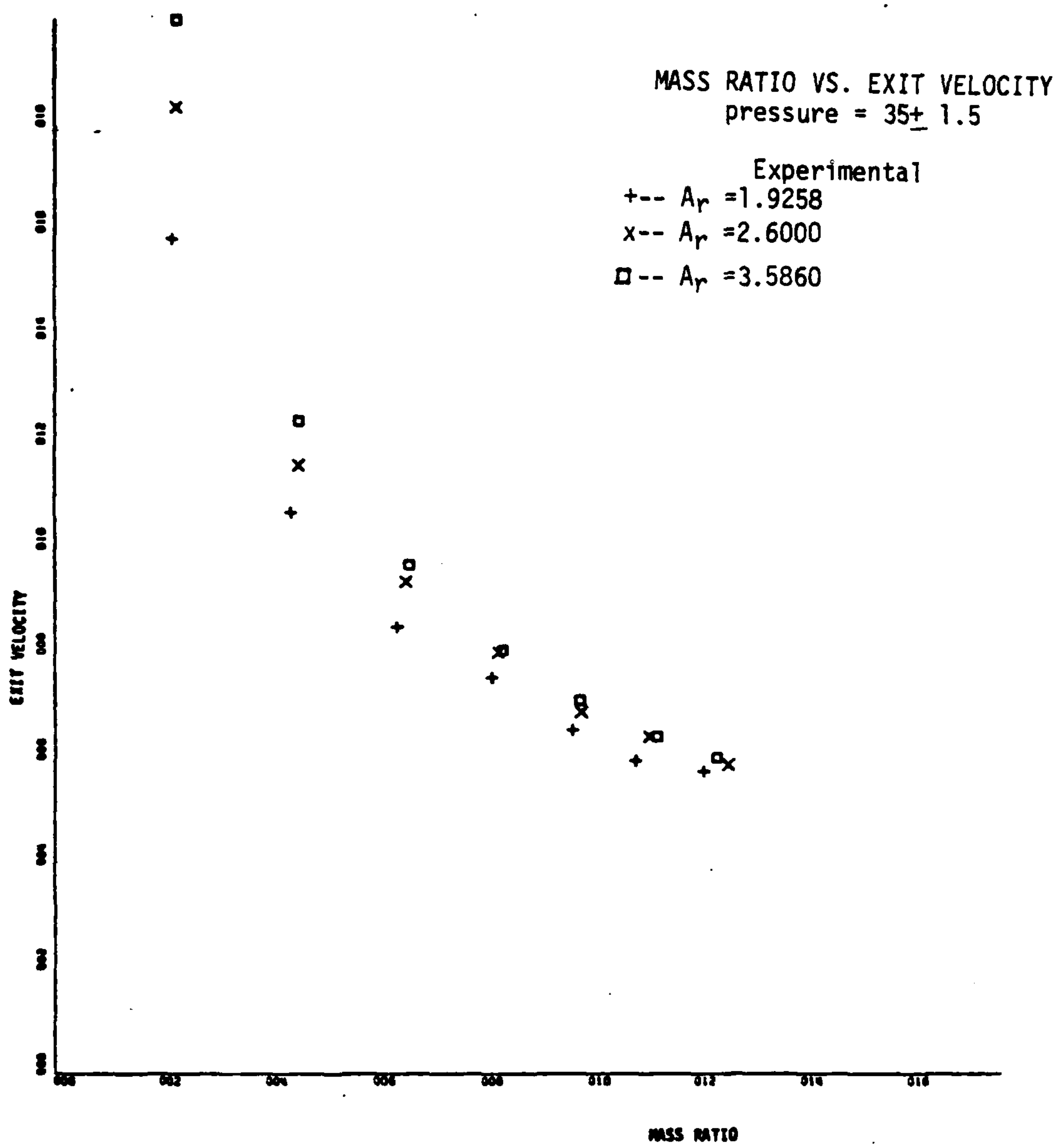
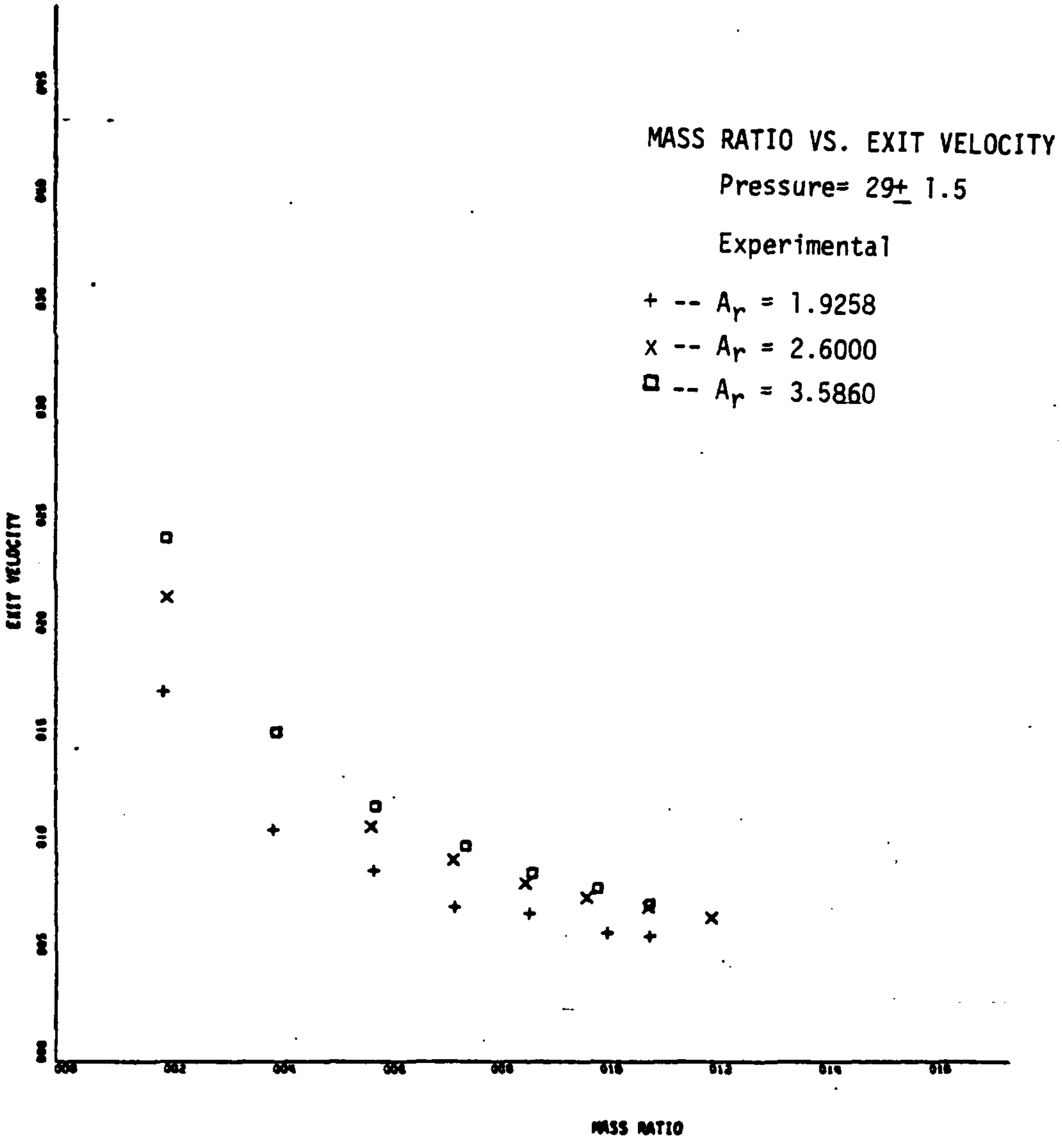
apparent flexibility of the type of pressure profile it was decided to employ a form of profile D of Figure 38. Thus instead of using the actual experimental pressure data as an input in the computer model, a profile resembling curve D was developed for each inlet pressure case.

It is apparent that within certain rather wide limits the Elliott computer model yields results that correspond within 10% to results obtained from the experiment. The general trends have been confirmed and their behavior has revealed nothing unexpected. The conclusion of Elliott [Ref. 1] has been largely substantiated. "It is very difficult to design a bad or a good dual-phase nozzle."



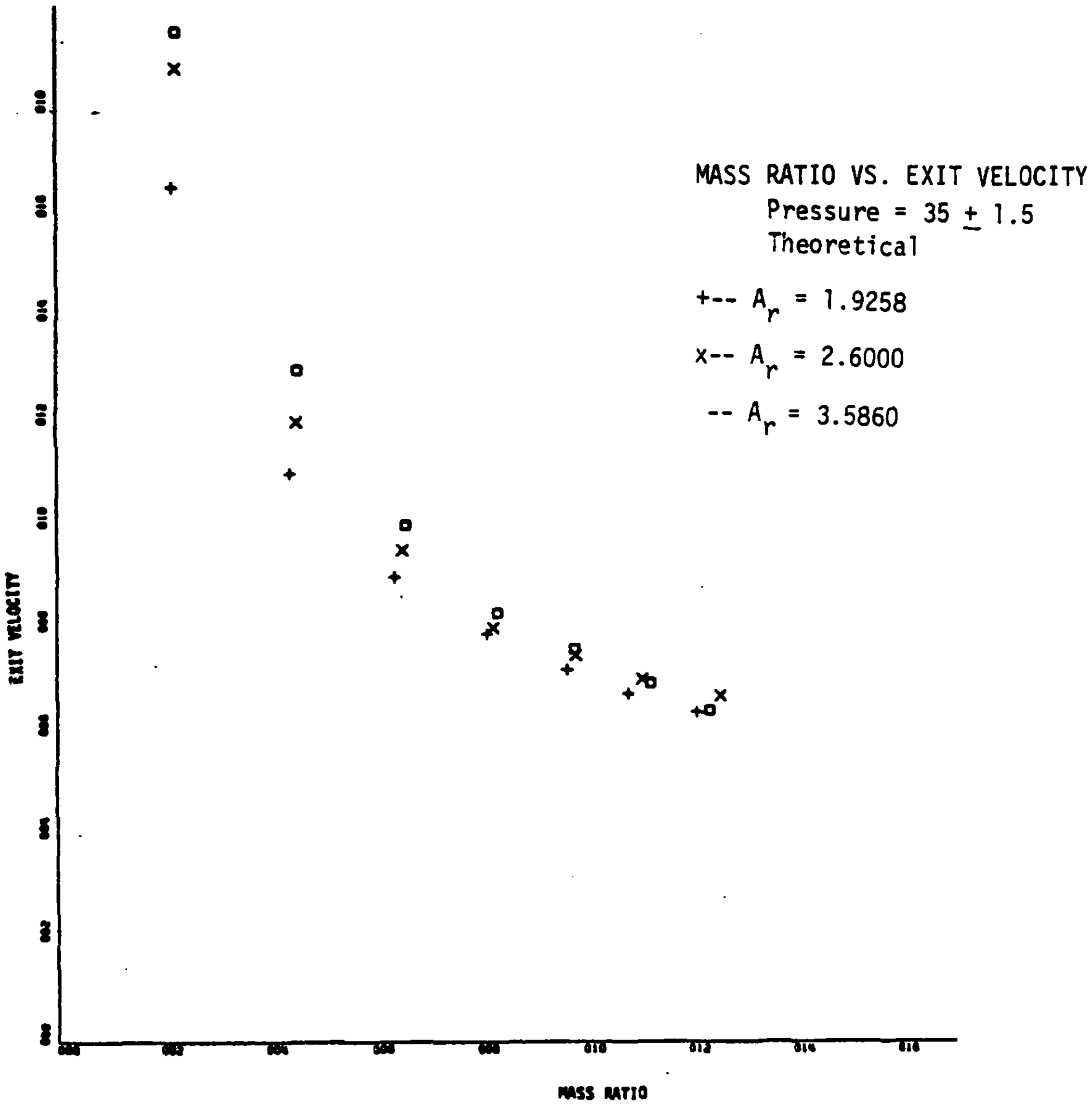
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 25. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Experimental



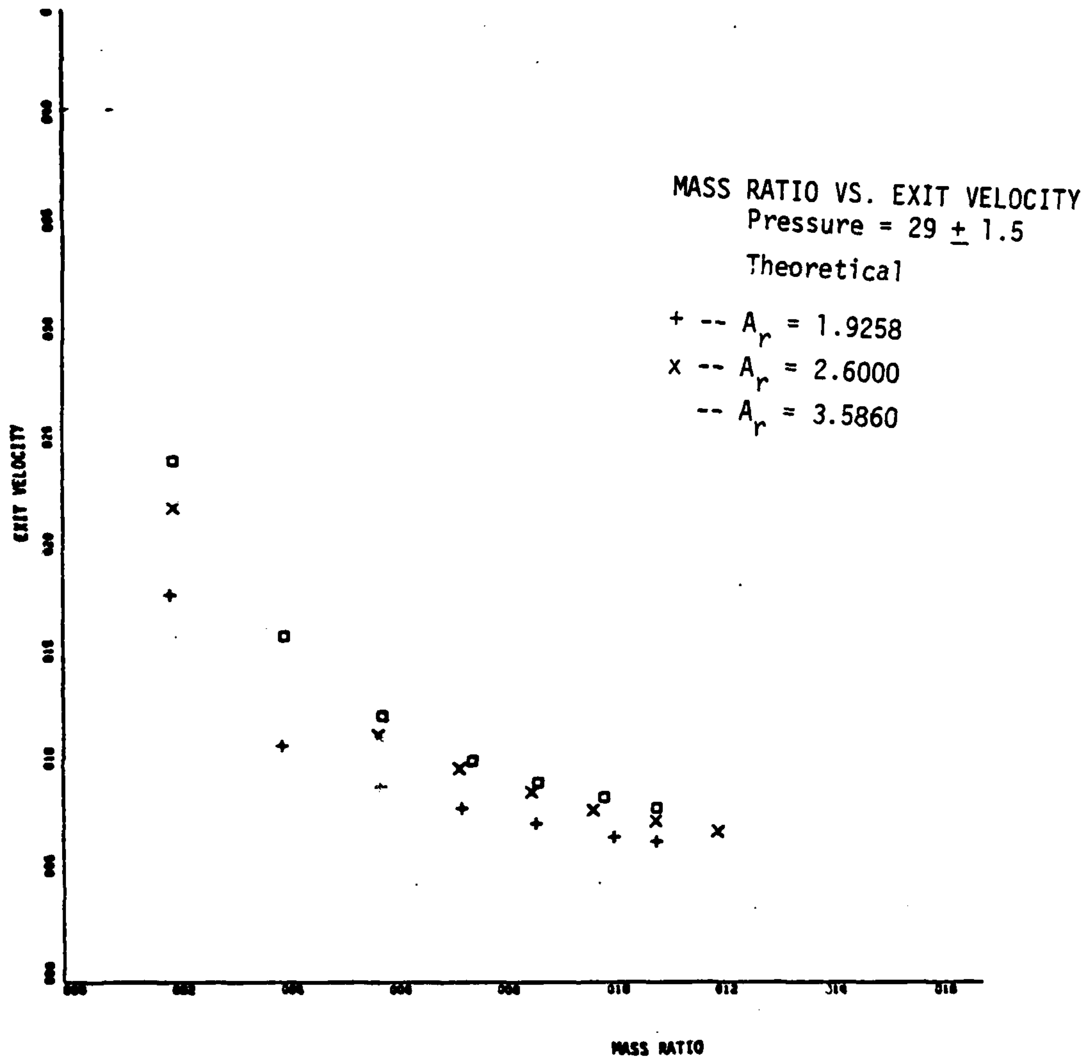
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 26. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Experimental



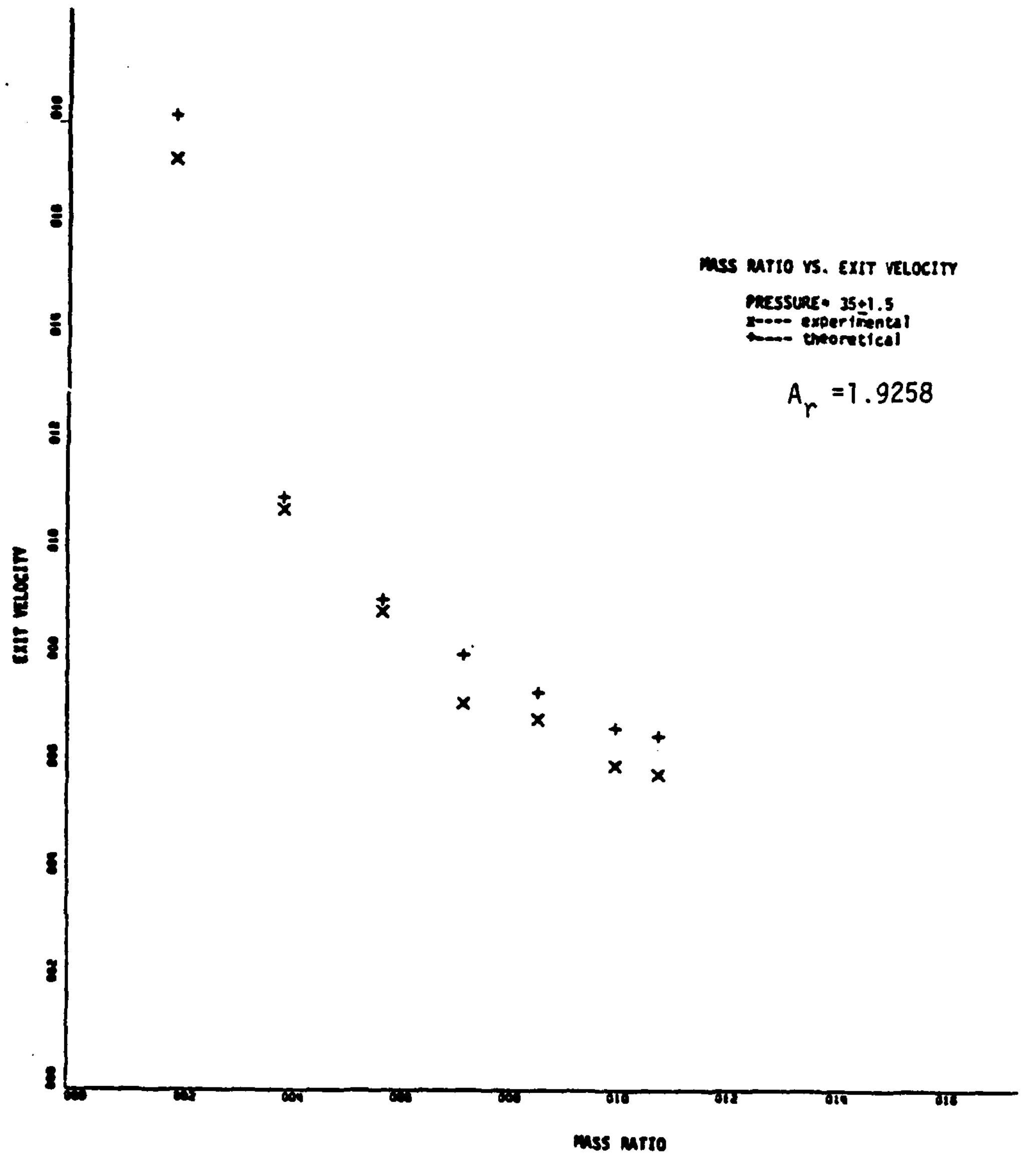
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 27. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Theoretical



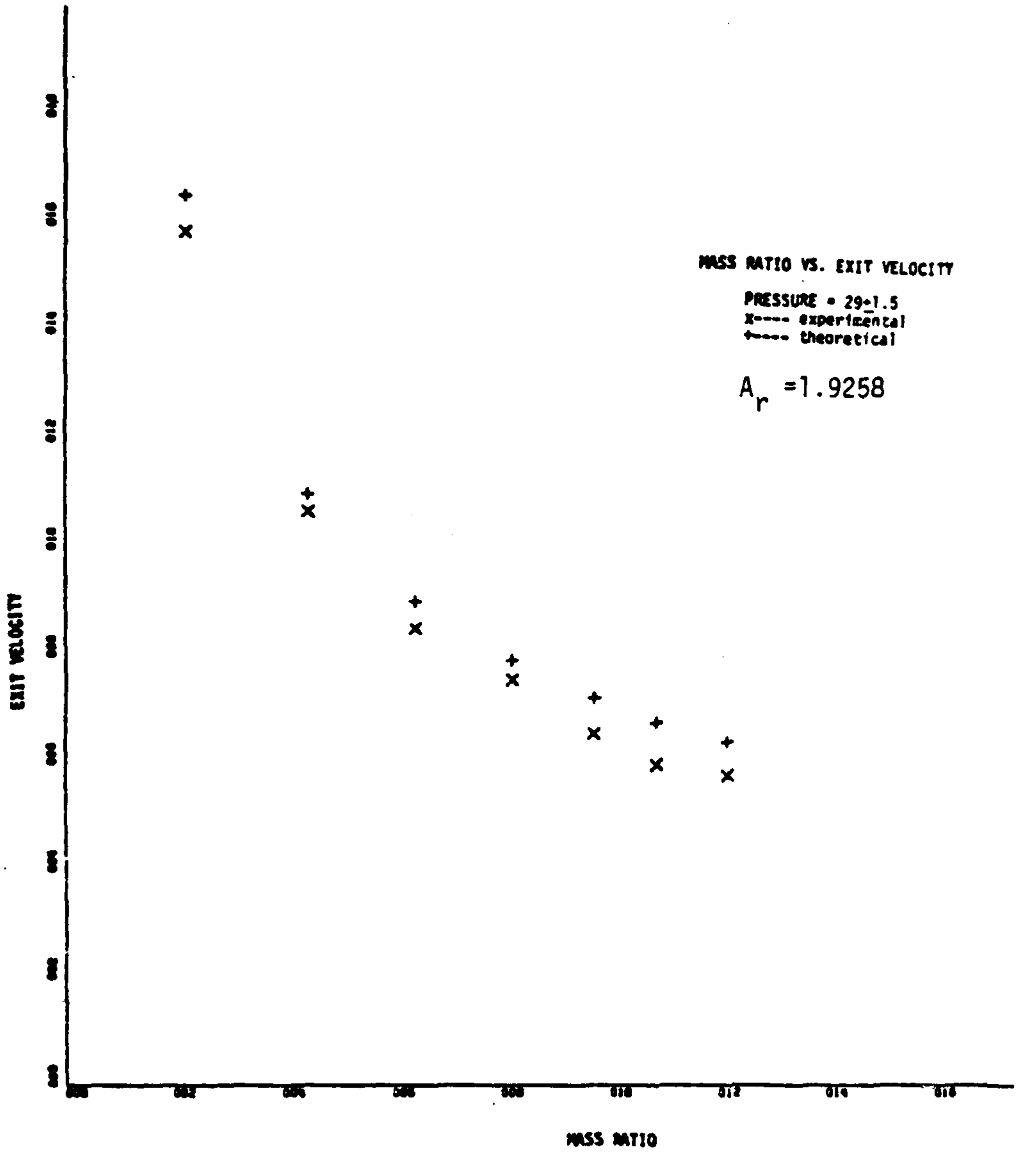
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 28. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Theoretical



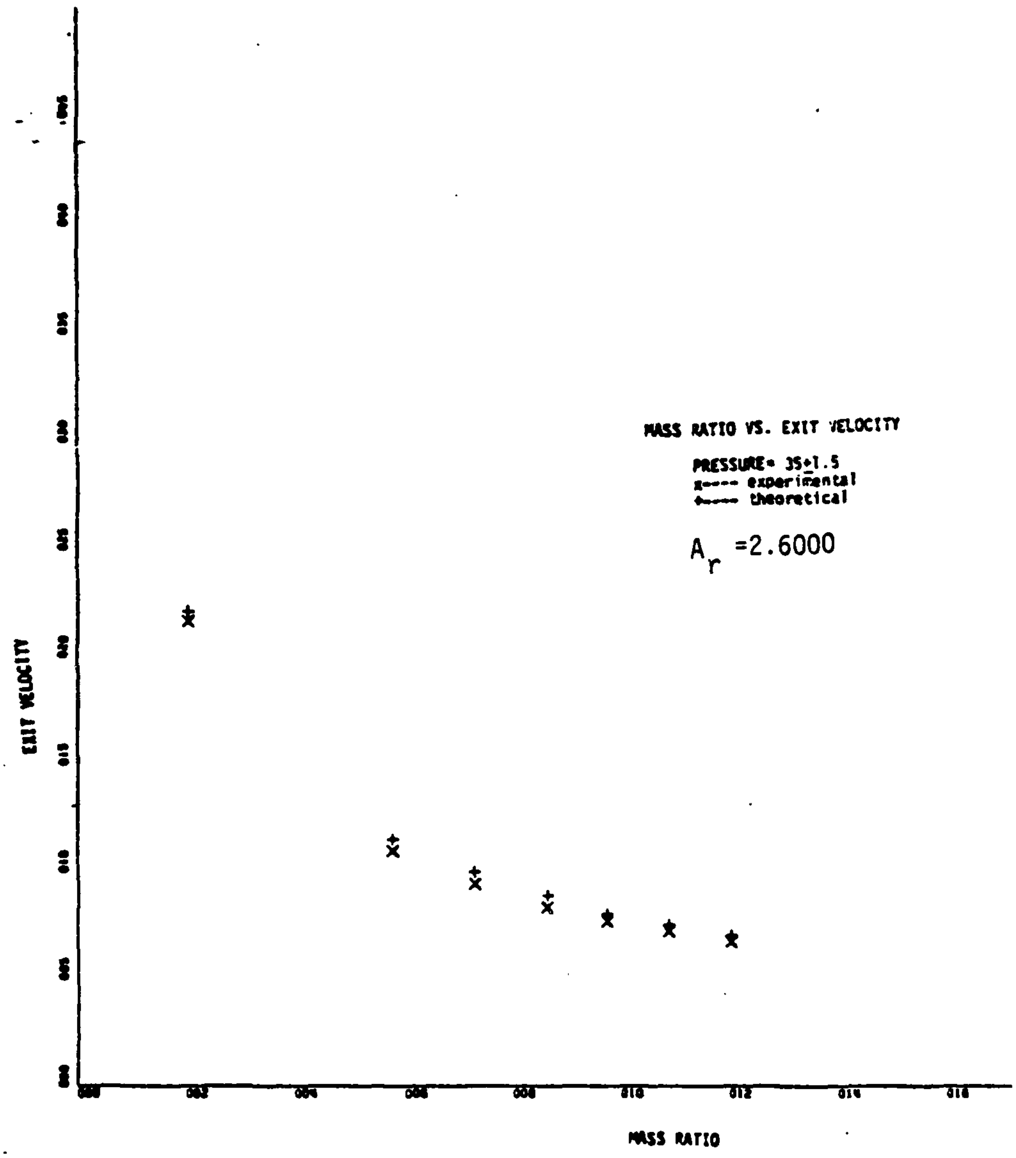
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 29. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Area = .34375



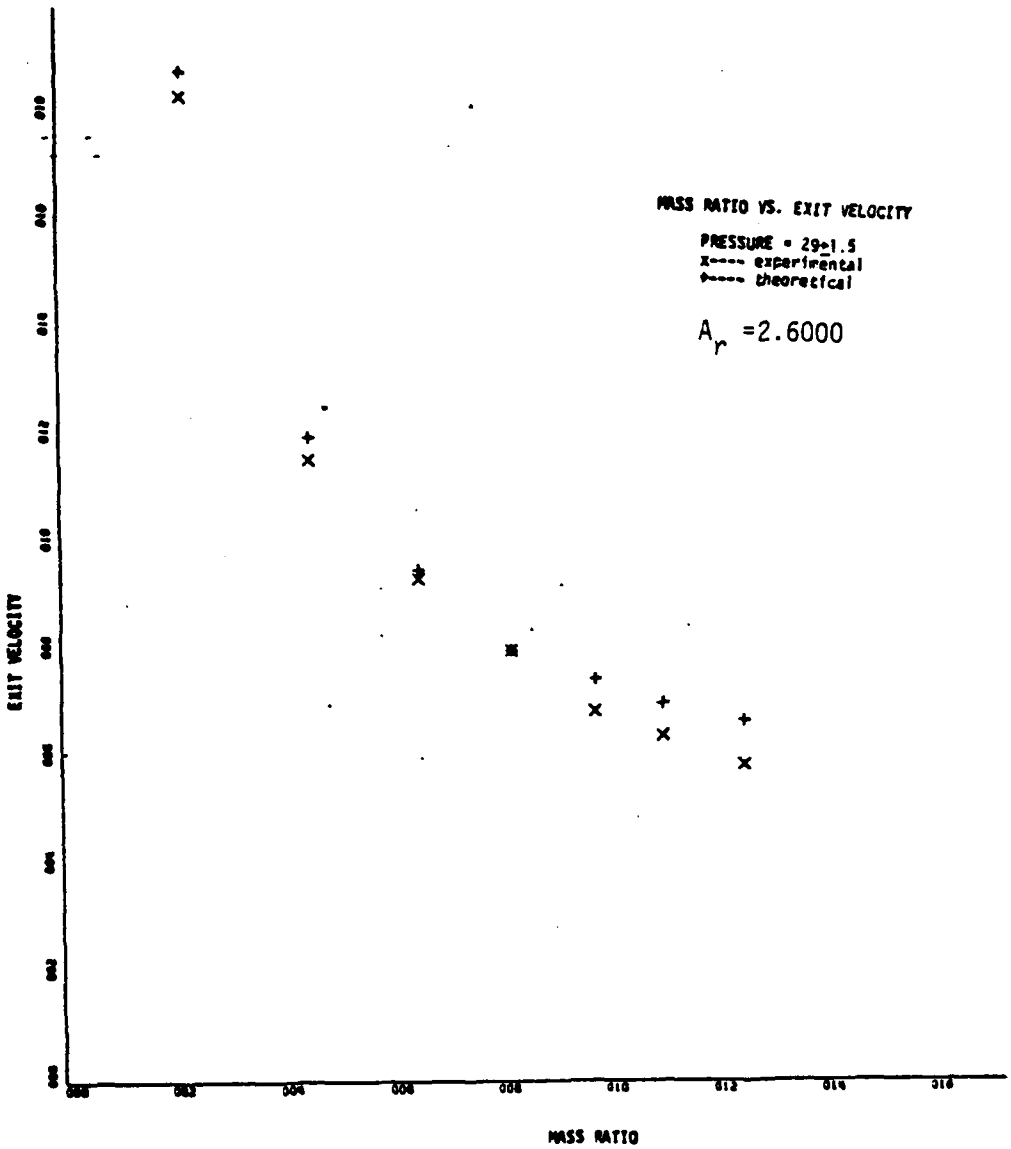
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 30. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Area = .84375



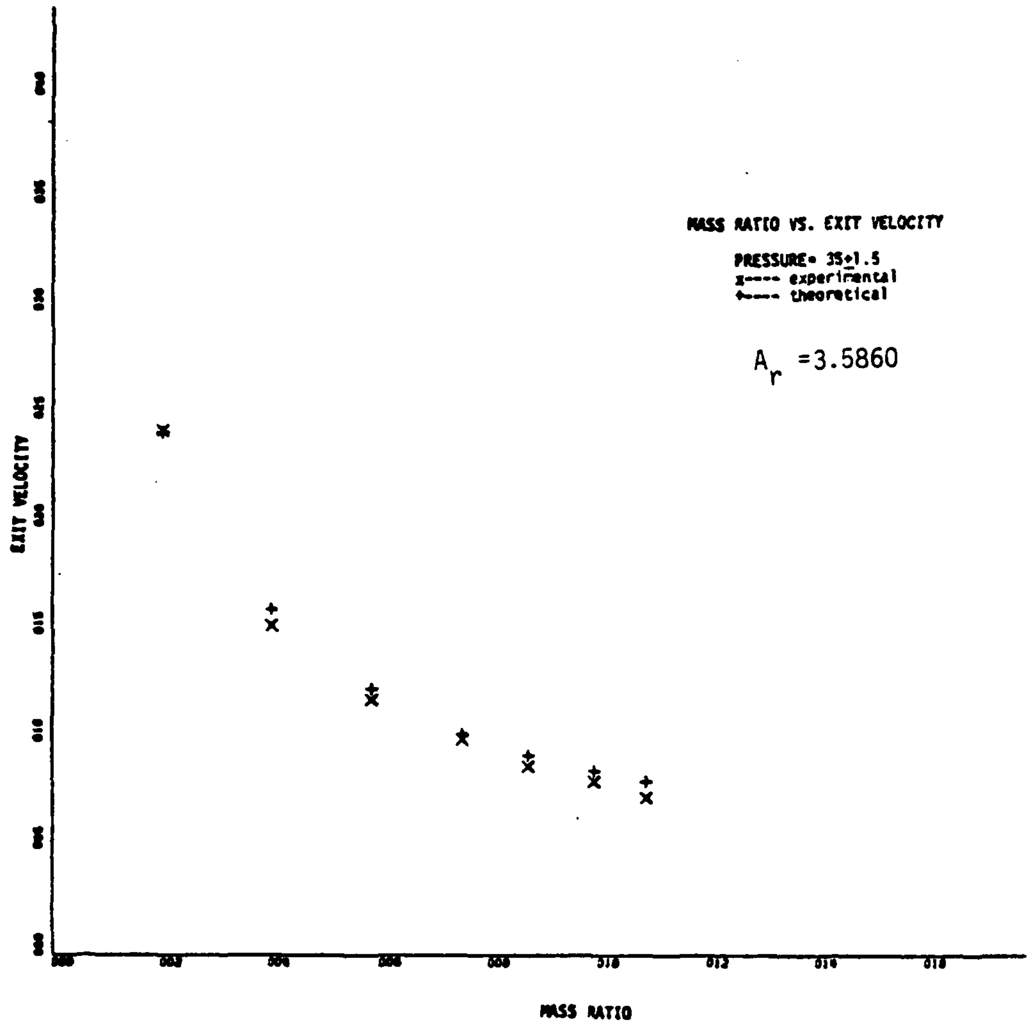
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 31. Mass Ratio vs. Exit Velocity at
Pressure = 35±1.5psi Area = .62500



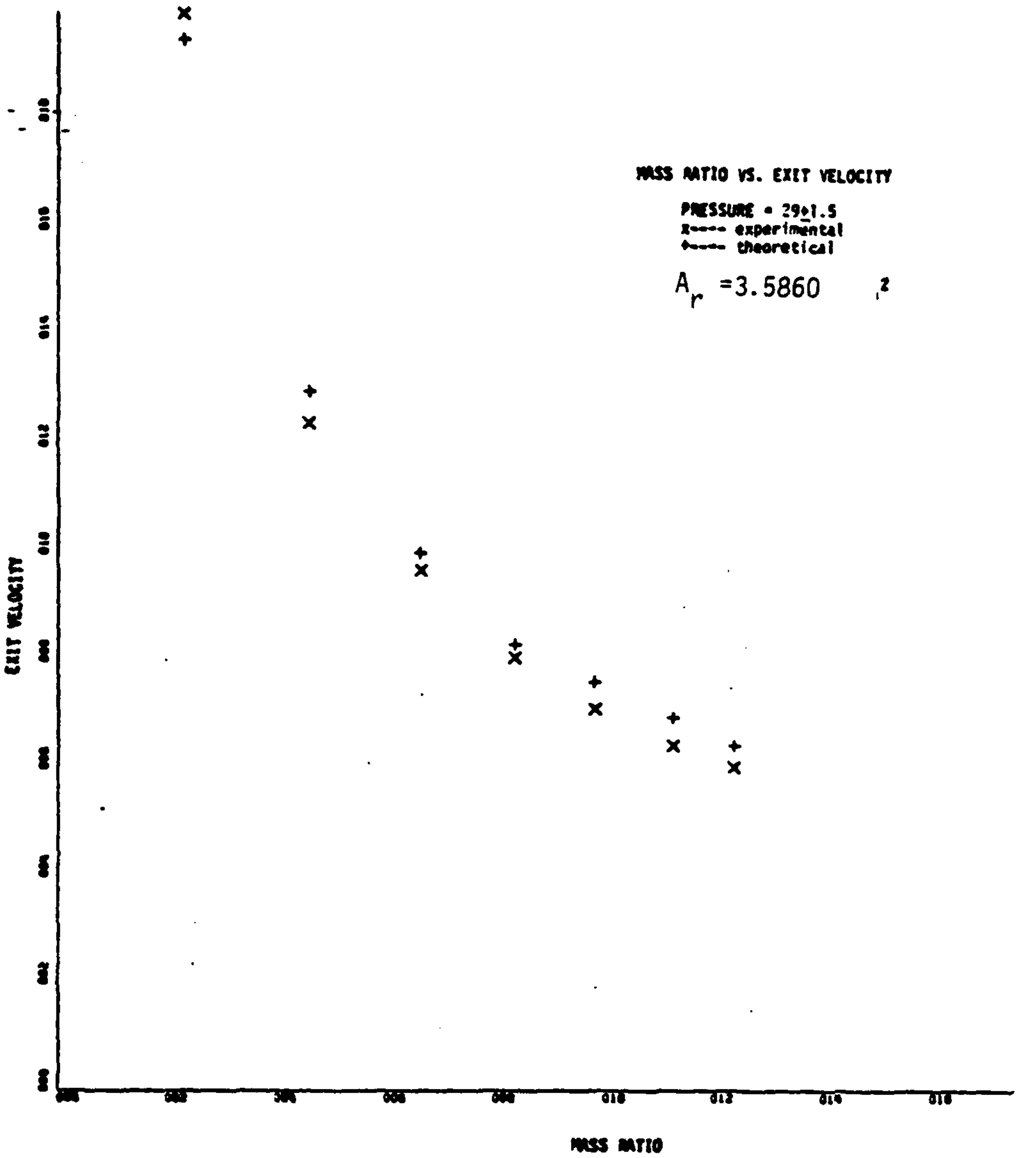
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 32. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Area = .62500



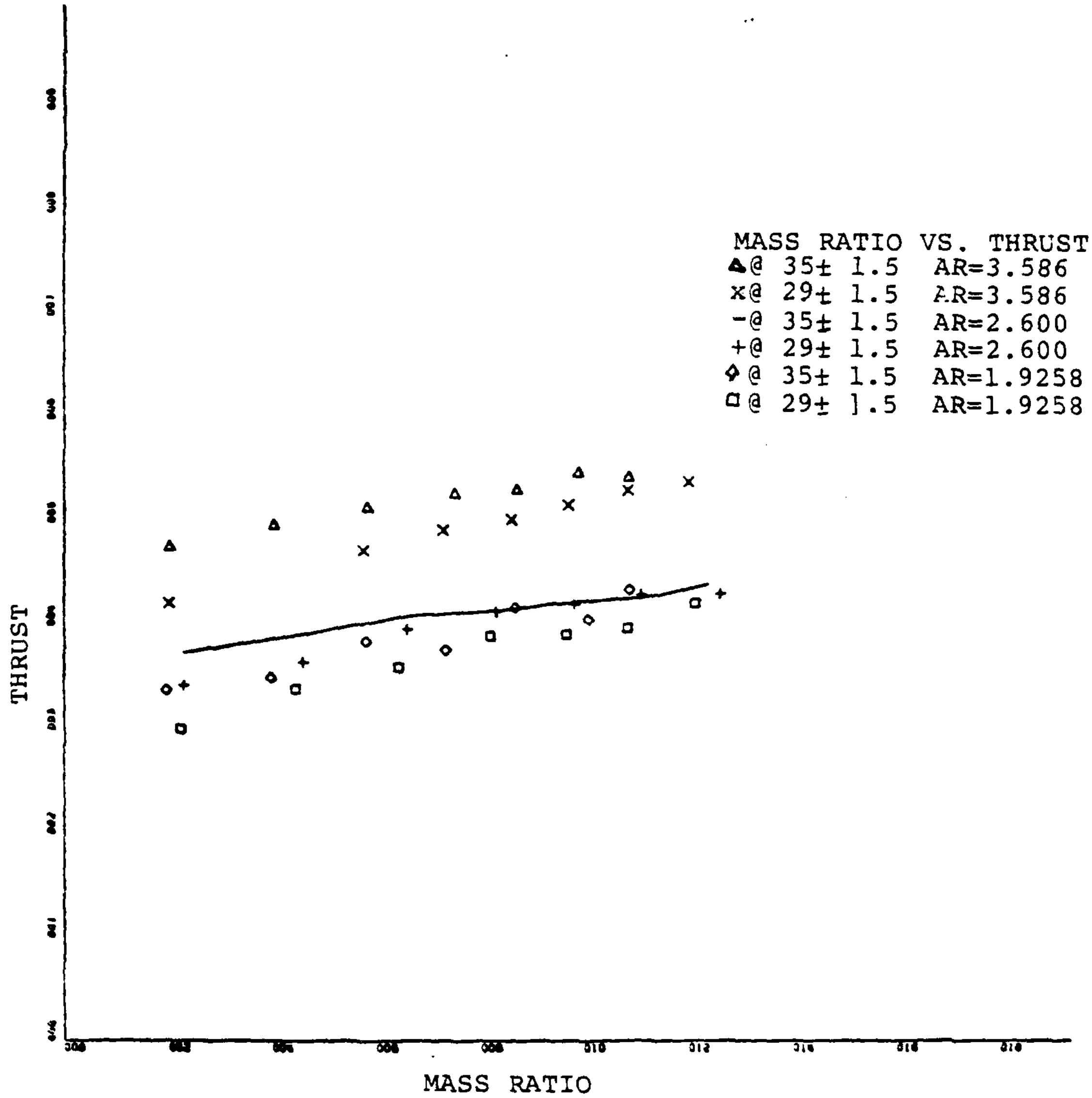
X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=5.00E+02 UNITS INCH.

Figure 33. Mass Ratio vs. Exit Velocity at Pressure = 35±1.5psi Area = .45313



X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=2.00E+02 UNITS INCH.

Figure 34. Mass Ratio vs. Exit Velocity at Pressure = 29±1.5psi Area = .45313



X-SCALE=2.00E+00 UNITS INCH.
Y-SCALE=1.00E+00 UNITS INCH.

Figure 35. Mass Ratio vs. Thrust Curve

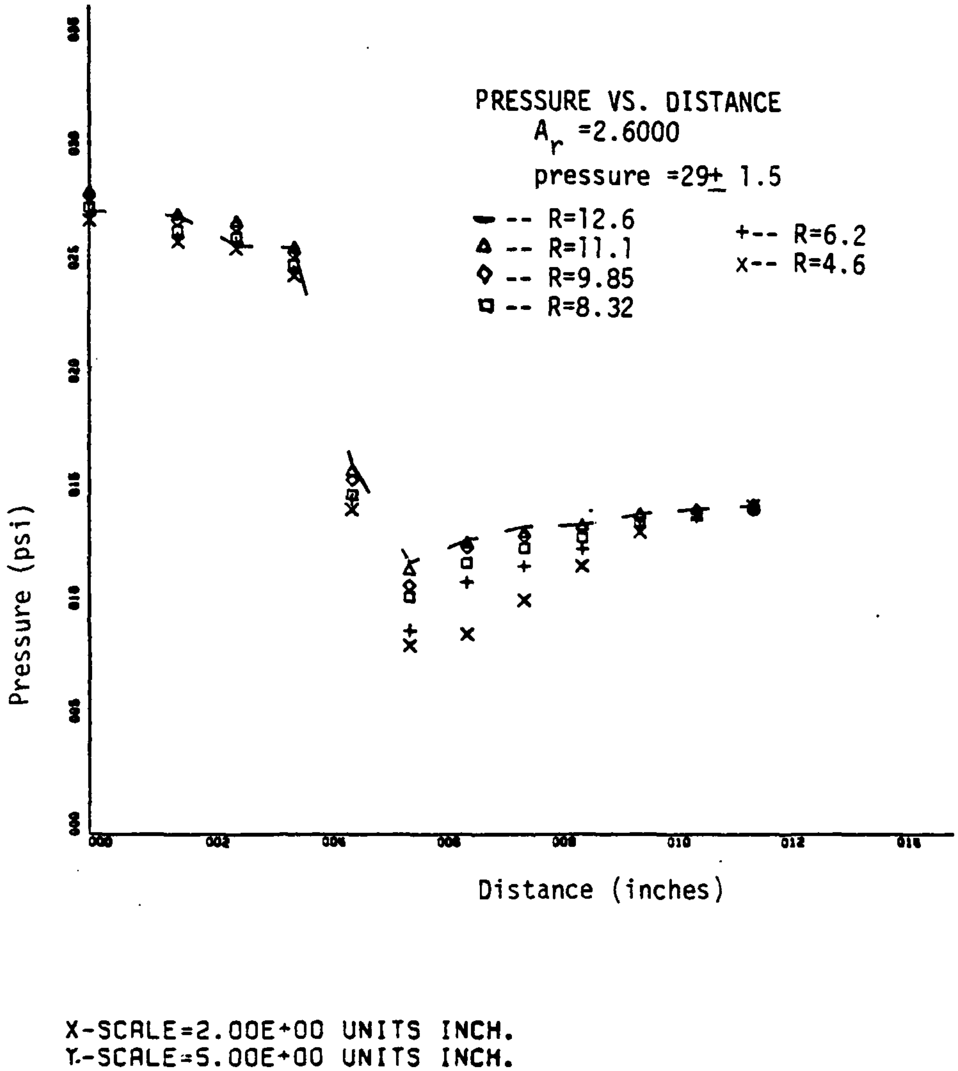


Figure 36. Pressure vs. Distance at Pressure = 29±1.5 Exit Area = .625 sq. in.

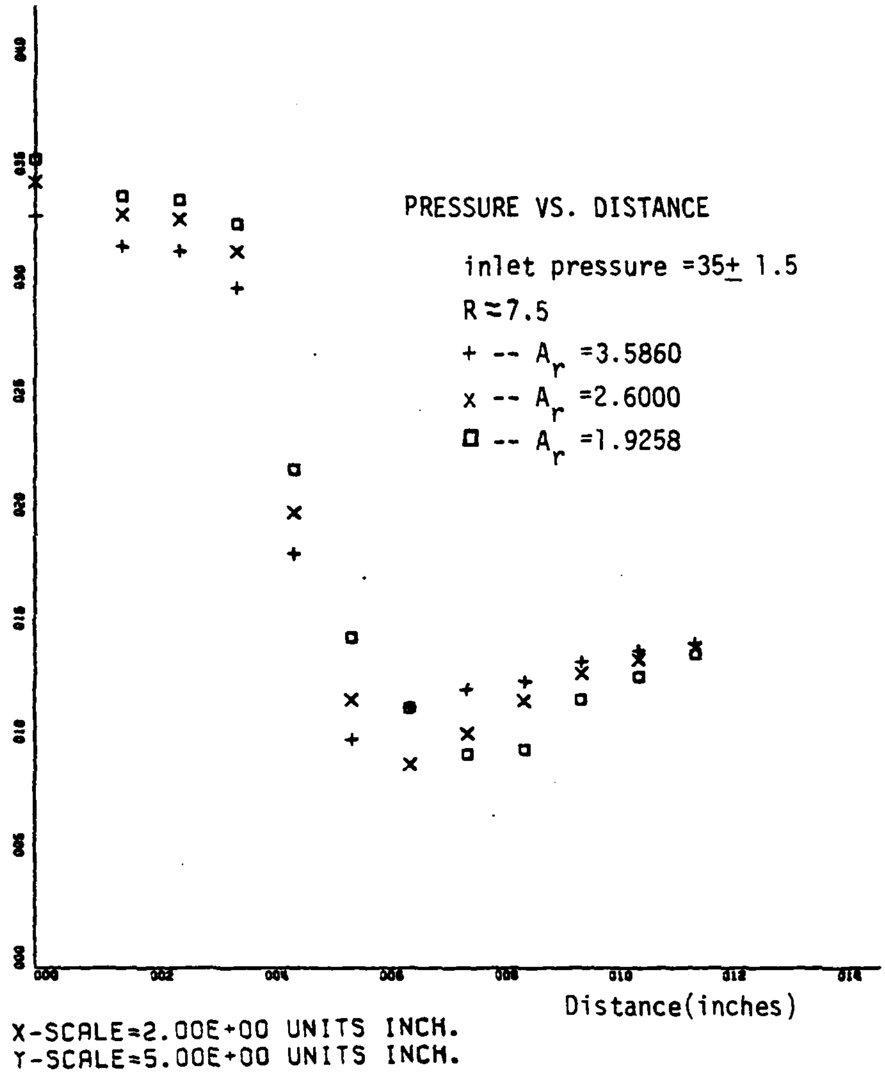


Figure 37. Pressure vs. Distance at
R ≈ 7.5 P = 35psi±1.5

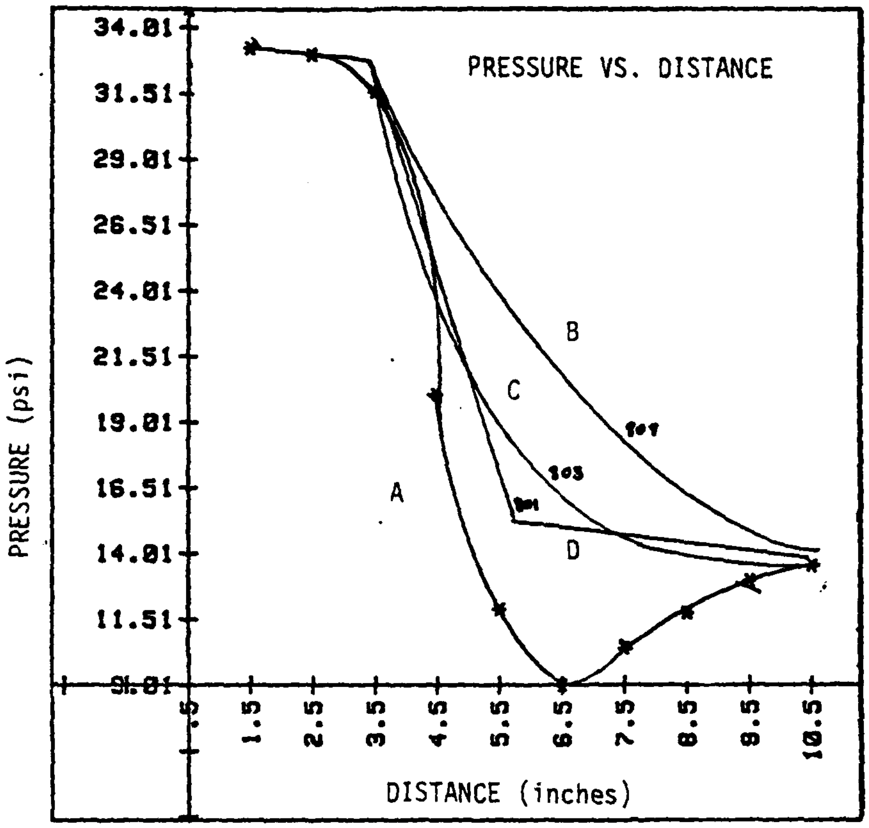


Figure 38. Various Pressure Profiles & Corresponding Exit Velocities

VIII. CONCLUSION

A set of experiments were conducted with an air-water mixture flowing at a mass ratio from 2 to 13. The experiments correlated well with a dual-phase two-component computer program. It appears that the program will permit prediction of the exit velocities to an accuracy of 10% for two-phase nozzles. At small nozzle area ratios, accuracies between theoretical and experimental are better; approximately 5%. All predicted velocities are higher than measured experimental values due to estimation of the drop size and the initial kinetic energy of the liquid at injection point.

It would be desirable to develop a drop size subroutine to better estimate varying drop size. The experimental system can be improved by velocity measurement devices at the inlet. Input of the gas and liquid velocities are necessary in the dual-phase two-component program and thus these measurement devices are vital for better accuracy.

Due to the insensitivity of the pressure distribution, it appears that any reasonable approximation to the pressure profile can be employed in the two-phase two-component flow program. For a given nozzle exit area and inlet pressure, a pressure distribution curve can be obtained through the experimental system. This distribution can therefore be used to obtain good results.

APPENDIX A: SAMPLE P(X) PROGRAM

```
$JOB
      REAL P(75),X(75),PX,FX
      INTEGER N,K,NP1,NX
      A=35.3694923
      B=5.6E5EE777
      C=14.39
      D=0.C4731
      E=.44480C3
      NX=75
      P1=35.0
      P2=8.C
      PREF=8.0
      XREF=10.C
      N=74
      NP1=N+1
      PX=(P1-P2)/380
      CC 10 K=1,N
         X(K)=7.7*(K-1)/(N-1)
         DX=7.7-X(K)
         IF (X(K).LE.0.7)P(K)=P2+PX*E*(855-A*(X(K)+.5)**B)
         IF (X(K).GT.0.7) P(K)=P2+PX*E*(C*DX+D*DX**4.9)
         IF(K .EQ.1)GO TO 1C
         FRAC=(P(K-1)-PREF)/(P(K-1)-P(K))
         IF (FRAC.GE.0 .AND.FRAC.LE.1)XXREF=X(K-1)+FRAC*(X(K)-X(K-1))
   10 CONTINUE
      FX=XREF/XXREF
      DC 15 K=1,N
   15    X(K)=FX*X(K)
      X(NP1)=1E5
      P(NP1)=1E5
      CC 20 K=1,75,3
   20    WRITE(6,100)P(K),X(K),P(K+1),X(K+1),P(K+2),X(K+2)
      STOP
  100 FCRMAT(6E12.6)
      END
```

APPENDIX B: SAMPLE HEAT CAPACITY PROGRAM

```
$JOB
      REAL PRESS(9),TABLE(20,20),P(20),TEMP(20),ANS(20),D1,D2,D3,D4,D5,
     1  D6,D7,D8,D9,M,W
      INTEGER N,J,I,Q,K,X
      DATA PRESS/.01,.4,.7,1.0,4.0,7.0,10.0,40.0,70.0/
      READ (5,100)((TABLE(J,I),I=1,10),J=1,16)
      DO 10 N=1,9
         PRESS(N)=PRESS(N)*14.696
10    CONTINUE
      DO 20 J=1,16
         DO 30 I=2,10
            TABLE(J,I)=TABLE(J,I)*.0685590
30       CONTINUE
20    CONTINUE
      M=0.0
      DO 91 J=1,16
         TEMP(J) =400.0 +M
         M=M+10.0
         W=0.0
         DO 90 I=1,11
            P(I)=W
            N=1
            Q=N+1
            W=100.0+W
15          IF (ABS(TEMP(J)- TABLE(N,1)).GT .001) GO TO 25
               Q=0
               GO TO 50
25          CONTINUE
            IF ((TEMP(J) .GT. TABLE(N,1)) .AND. (TEMP(J) .LT. TABLE(Q,1)))
     1         GO TO 50
               N=1+N
               Q=N+1
               GO TO 15
50          CONTINUE
            K=2
            X=K+1
            IF(P(I).GT. .0001)GO TO 49
               X=0
               GO TO 60
```

```
45    IF(ABS(P(I) -PRESS(K)).GT..001) GO TO 55
        X=C
        GO TO 60
55    CONTINUE
      IF ((P(I) .GT. PRESS(K)) .AND. (P(I) .LT. PRESS(X))) GO TO 60
        K=1+K
        X=K+1
        GO TO 55
60    CONTINUE
      IF((C.NE. C) .OR. (X .NE. 0))GO TO 61
        ANS(I)=TABLE (N,K)
        GO TO 90
      CONTINUE
61    IF(C .NE. C)  GO TO 63
        D1 = TABLE(N,K)-TABLE(N,X)
        D7 = PRESS(K-1) -PRESS(X-1)
        D8 =PRESS(K-1)-P(I)
        D9 =(D8/D7)*D1
        ANS(I)=D9+TABLE(N,K)
        GO TO 90
63    CONTINUE
      IF ().NE. C) GO TO 70
        D1 = (TABLE(N,K)-TABLE(Q,K))
        D3 = TABLE(N,1)-TABLE(Q,1)
        D4 =TABLE(N,1) -TEMP(J)
        D9 =(D4/D3)*D1
        ANS(I) =D9+(TABLE(N,K))
        GO TO 90
70    CONTINUE
      D1 =TABLE(N,K)-TABLE(Q,K)
      D2=TABLE(N,X)-TABLE(Q,X)
      D3=TABLE(N,1)-TABLE(Q,1)
      D4=TABLE(N,1)-TEMP(J)
```

```
      C5=(E4/D3)*D1
      D6=(E4/D3)*D2
      D10=D5+TABLE(N,K)
      D11=D6+TABLE(N,K)
      D7=(PRESS(K-1)-PRESS(X))
      D8=PRESS(K-1)-P(I)
      D9=(D8/D7)*(D10-D11)
      ANS(I)=D9+D10
 90   CONTINUE
      WRITE(6,150)TEMP(J)
      WRITE(6,200)P(1),ANS(1),P(2),ANS(2),P(3),ANS(3)
      WRITE(6,200)P(4),ANS(4),P(5),ANS(5),P(6),ANS(6)
      WRITE(6,200)P(7),ANS(7),P(8),ANS(8),P(9),ANS(9)
      WRITE(6,250)P(10),ANS(10),P(11),ANS(11)
 91   CONTINUE
      STOP
 100  FORMAT(10F7.4)
 150  FORMAT(F12.6)
 200  FORMAT  (6F12.6)
 250  FORMAT  (4F12.6)
      END
$ENTRY
360.0   3.4923 3.4935 3.3020 3.5062 3.5495 3.5950 3.6427 4.256  5.132
396.0   3.4928 3.4971 3.5005 3.5038 3.5379 3.5731 3.6095 4.036  4.559
414.0   3.4933 3.4972 3.5002 3.5032 3.5337 3.5651 3.5972 3.963  4.342
432.0   3.4938 3.4973 3.5000 3.5028 3.5302 3.5584 3.5971 3.906  4.265
450.0   3.4946 3.4978 3.5003 3.5027 3.5277 3.5531 3.5769 3.860  4.166
468.0   3.4954 3.4983 3.5005 3.5028 3.5255 3.5485 3.5719 3.822  4.090
486.0   3.4964 3.4990 3.5011 3.5031 3.5240 3.5450 3.5663 3.790  4.025
504.0   3.4976 3.5000 3.5019 3.5039 3.5228 3.5420 3.5614 3.763  3.970
522.0   3.4990 3.5012 3.5030 3.5047 3.5222 3.5398 3.5576 3.741  3.926
540.0   3.5006 3.5026 3.5043 3.5059 3.5220 3.5383 3.5546 3.722  3.889
558.0   3.5025 3.5044 3.5059 3.5074 3.5223 3.5374 3.5525 3.705  3.857
576.0   3.5045 3.5063 3.5076 3.5091 3.5229 3.5369 3.5508 3.692  3.831
594.0   3.5069 3.5085 3.5098 3.5112 3.5240 3.5371 3.5500 3.680  3.808
612.0   3.5094 3.5109 3.5121 3.5134 3.5254 3.5375 3.5497 3.671  3.788
630.0   3.5122 3.5137 3.5148 3.5160 3.5273 3.5386 3.5460 3.662  3.771
720.0   3.5305 3.5316 3.5325 3.5333 3.5416 3.5500 3.5583 3.640  3.717
```

APPENDIX C: SAMPLE MOLECULAR WEIGHT PROGRAM

```
$JOB
      REAL PRESS(9),TABLE(20,20),P(20),TEMP(20),ANS(20),D1,D2,D3,D4,D5,
     1     D6,D7,D8,D9,M,W,MWS(20)
      INTEGER N,J,I,Q,K,X
      DATA PRESS/.01,.4,.7,1.0,4.0,7.0,10.0,40.0,70.0/
      READ (5,100)((TABLE(J,I),I=1,10),J=1,16)
      DO 10 N=1,9
         PRESS(N)=PRESS(N)*14.696
 10   CONTINUE
      DO 20 J=1,16
         DO 30 I=2,10
            TABLE(J,I)=TABLE(J,I)*.0807223
 30      CONTINUE
 20   CONTINUE
      M=0.0
      DO 92 J=1,16
         TEMP(J) =400.0 +M
         M=M+10.0
         W=0.0
         DO 91 I=1,11
            P(I)=W
            N=1
            Q=N+1
            W=100.0+W
 15         IF (ABS(TEMP(J)- TABLE(N,1)).GT .001) GO TO 25
               Q=0
               GO TO 50
 25         CONTINUE
            IF ((TEMP(J) .GT. TABLE(N,1)) .AND. (TEMP(J) .LT. TABLE(Q,1)))
     1         GO TO 50
               N=1+N
               Q=N+1
               GO TO 15
 50         CONTINUE
            K=2
            X=K+1
            IF(P(I).GT. .0001)GO TO 49
               X=0
               GO TO 60
 49         IF(ABS(P(I) -PRESS(K)).GT..001) GO TO 55
               X=0
               GO TO 60
```

```
55      CONTINUE
        IF ((F(I) .GT. PRESS(K)) .AND. (F(I) .LT. PRESS(X))) GO TO 60
          K=1+K
          X=K+1
          GO TO 55
60      CONTINUE
        IF((C.NE. 0) .OR. (X .NE. 0))GO TO 61
          ANS(I)=TABLE (N,K)
          GO TO 90
        CONTINUE
61      IF(C .NE. C)  GO TO 63
          D1 = (TABLE(N,K)-TABLE(N,X))
          D7 = (PRESS(K-1) -PRESS(X-1))
          D8 =PRESS(K-1)-P(I)
          D5 =ABS((D8/D7)*D1)
          ANS(I)=D5+TABLE(N,K)
          GO TO 90
63      CONTINUE
        IF (?.NE. C) GO TO 70
          D1 = (TABLE(N,K)-TABLE(C,K))
          D3 = TABLE(N,1)-TABLE(C,1)
          D4 =TABLE(N,1) -TEMP(J)
          D5 =ABS((D4/D3)*D1)
          ANS(I) =(TABLE(N,K))-D9
          GO TO 90
70      CONTINUE
        D1 =TABLE(N,K)-TABLE(C,K)
        D2=TABLE(N,X)-TABLE(O,X)
        D3=TABLE(N,1)-TABLE(O,1)
        D4=TABLE(N,1)-TEMP(J)
```

```
      D5=ABS((D4/D3)*D1)
      D6=ABS((D4/D3)*D2)
      D10=TABLE(N,K)-D5
      D11=TABLE(N,X)-D6
      D7=(PRESS(K-1)-PRESS(X))
      D8=PRESS(K-1)-P(I)
      D9=ABS((D8/D7)*(D10-D11))
      ANS(I)=D9+D10
90    IF (P(I).LT..001)P(I)=.00001
      MWS(I)=(.3685*TEMP(J)*ANS(I)/P(I))
91    CONTINUE
      WRITE(6,150)TEMP(J)
      WRITE(6,200)P(1),MWS(1),P(2),MWS(2),P(3),MWS(3)
      WRITE(6,200)P(4),MWS(4),P(5),MWS(5),P(6),MWS(6)
      WRITE(6,200)P(7),MWS(7),P(8),MWS(8),P(9),MWS(9)
      WRITE(6,250)P(10),MWS(10),P(11),MWS(11)
92    CONTINUE
      STOP
100   FORMAT(9F7.4,F7.3)
150   FORMAT(F12.6)
200   FORMAT (6F12.6)
250   FORMAT (4F12.6)
      END
$ENTRY
360.0   .01365  .54648  .95700  1.3681  5.5110  9.7130  13.976  60.13   112.7
356.0   .01241  .49666  .86860  1.2429  4.9960  8.7860  12.613  52.88   96.30
414.0   .01187  .47512  .83160  1.1985  4.7730  8.3880  12.031  49.99   90.19
432.0   .01138  .45519  .79680  1.1390  4.5700  8.0260  11.503  47.48   84.99
450.0   .01092  .43695  .76490  1.0930  4.3840  7.6940  11.021  45.18   80.48
468.0   .01050  .42011  .73540  1.0509  4.2120  7.3850  10.579  43.15   76.51
486.0   .01011  .40453  .70810  1.0117  4.0540  7.1080  10.172  41.31   72.98
504.0   .00975  .39006  .68273  0.9755  3.9070  6.8480   9.797  39.64   69.81
522.0   .00941  .37660  .65910  0.9417  3.7710  6.6170   9.449  38.12   66.95
540.0   .00910  .36403  .63710  0.9102  3.6440  6.3830   9.125  36.72   64.34
558.0   .00881  .35227  .61650  0.8808  3.5250  6.1730   8.824  35.42   61.96
576.0   .00853  .34126  .59720  0.8532  3.4140  5.9770   9.542  34.22   59.77
594.0   .00827  .33090  .57910  0.8273  3.3110  5.7940   8.270  33.11   57.74
612.0   .00802  .32117  .56210  0.8029  3.2120  5.6210   8.030  32.07   55.86
630.0   .00780  .31198  .54600  0.7800  3.1196  5.4590   7.737  31.10   54.11
720.0   .00683  .27297  .47770  0.6823  2.7277  4.7710   6.811  27.04   46.89
```

APPENDIX D: SAMPLE PROPERTY TABLE

$ENTRY							CAG 0010
400.0							CAG 0020
0.0	.2484	100.0	.2534	200.0	.2571		CAG 0030
300.0	.2626	400.0	.2578	500.0	.2730		CAG 0040
600.0	.2779	700.0	.2842	800.0	.2962		
900.0	.3003	1000.0	.3053		1.E5	1.E5	CAG 0050
410.0							CAG 0060
0.0	.2484	100.0	.2532	200.0	.2569		CAG 0070
300.0	.2621	400.0	.2672	500.0	.2721		CAG 0080
600.0	.2769	700.0	.2823	800.0	.2918		CAG 0090
900.0	.2976	1000.0	.3030		1.E5	1.E5	CAG 0100
420.0							CAG 0110
0.0	.2484	100.0	.2531	200.0	.2556		CAG 0120
300.0	.2616	400.0	.2665	500.0	.2712		CAG 0130
600.0	.2759	700.0	.2815	800.0	.2894		CAG 0140
900.0	.2950	1000.0	.3000		1.E5	1.E5	CAG 0150
430.0							CAG 0160
0.0	.2484	100.0	.2529	200.0	.2564		CAG 0170
300.0	.2612	400.0	.2659	500.0	.2734		CAG 0180
500.0	.2748	700.	.2801	800.0	.2869		CAG 0190
900.0	.2924	1000.0	.2970		1.E5	1.E5	CAG 0200
440.0							CAG 0210
0.0	.2484	100.0	.2527	200.0	.2561		CAG 0220
300.	.2607	400.0	.2651	500.0	.2695		CAG 0230
600.0	.2737	700.0	.2787	800.0	.2847		CAG 0240
900.0	.2898	1000.0	.2942		1.E5	1.E5	CAG 0250
450.0							CAG 0260
0.0	.2484	100.0	.2526	200.0	.2559		CAG 0270
300.0	.2602	400.0	.2645	500.0	.2686		CAG 0280
600.0	.2726	700.0	.2774	800.0	.2825		CAG 0290
900.0	.2872	1000.0	.2915		1.E5	1.E5	CAG 0300
460.0							CAG 0310
0.0	.2484	100.0	.2524	200.0	.2556		CAG 0320
300.0	.2597	400.0	.2638	500.0	.2678		CAG 0330
600.0	.2716	700.0	.2759	800.0	.2804		CAG 0340

```
900.0          .2848          1000.0         .2833                         1.E5          1.E5CAG 0350
470.0                                                                                        CAG 0360
0.0            .2484          100.0          .2522          200.0          .2554             CAG 0370
300.0          .2594          400.0          .2631          500.0          .2668             CAG 0380
600.0          .2706          700.0          .2744          800.0          .2786             CAG 0390
900.0          .2826          1000.0         .2863                         1.E5          1.E5CAG 0400
+.470000E+03                                                                                 CAG 0410
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+.000000E+00+.460000E+00+.100000E+04+.460000E+00+.100000E+06+.100000E+06CBT 0940
400.0                                                                                        WAG 0950
0.0            28.010         100.0          28.210         200.0          28.376            WAG 0960
300.0          28.540         400.0          28.725         500.0          29.120            WAG 0970
600.0          29.244         700.0          29.552         900.0          29.590            WAG 0980
900.0          29.773         1000.0         29.843                        1.E5          1.E5WAG 0990
410.0                                                                                        WAG 1000
0.0            28.010         100.0          28.198         200.0          28.355            WAG 1010
300.0          28.544         400.0          28.711         500.0          29.032            WAG 1020
600.0          29.150         700.0          29.423         800.0          29.462            WAG 1030
900.0          29.615         1000.0         29.780                        1.E5          1.E5WAG 1040
420.0                                                                                        WAG 1050
0.0            28.010         100.0          28.186         200.0          28.332            WAG 1060
```

```
300.0        28.508      400.0       28.730      500.0         28.942          WAG  1070
600.0        29.055      700.0       29.242      800.0         29.331          WAG  1080
900.0        29.460      1000.0      29.500                1.E5           1.E5WAG  1090
430.0                                                                          WAG  1100
0.0          28.010      100.0       28.175      200.0         28.319          WAG  1110
300.0        28.472      400.0       28.559      500.0         28.953          WAG  1120
600.0        28.958      700.0       29.147      800.0         29.200          WAG  1130
900.0        29.312      1000.0      29.425                1.E5           1.E5WAG  1140
440.0                                                                          WAG  1150
0.0          28.010      100.0       28.153      200.0         28.298          WAG  1160
300.0        28.436      400.0       28.575      500.0         28.765          WAG  1170
600.0        28.863      700.0       29.012      800.0         29.070          WAG  1180
900.0        29.165      1000.0      29.255                1.E5           1.E5WAG  1190
450.0                                                                          WAG  1200
0.0          28.010      100.0       28.151      200.0         28.266          WAG  1210
300.0        28.400      400.0       28.543      500.0         28.680          WAG  1220
600.0        28.768      700.0       28.882      800.0         28.940          WAG  1230
900.0        29.020      1000.0      29.010                1.E5           1.E5WAG  1240
460.0                                                                          WAG  1250
0.0          28.010      100.0       28.140      200.0         28.244          WAG  1260
300.0        28.363      400.0       28.442      500.0         28.595          WAG  1270
600.0        28.677      700.0       28.750      800.0         28.817          WAG  1280
900.0        28.880      1000.0      28.940                1.E5           1.E5WAG  1290
470.0                                                                          WAG  1300
0.0          28.010      100.0       28.123      200.0         28.222          WAG  1310
300.0        28.127      400.0       28.422      500.0         28.517          WAG  1320
600.0        28.587      700.0       28.548      800.0         28.700          WAG  1330
900.0        28.750      1000.0      28.700                1.E5           1.E5WAG  1340
+.480000E+03                                                                   WAG  1350
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+.570000E+03+.102440E+04+.100000E+06+.100000E+06                        LB   1990
400.0       .015        410.0       .017        420.0       .019        PBO  2000
430.0       .021        440.0       .026        450.0       .035        PBO  2010
460.0       .045        470.0       .055        480.0       .065        PBO  2020
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430.0       62.418      440.0       62.418      450.0       62.418      ROAL 2100
460.0       62.419      470.0       62.418      480.0       62.418      ROAL 2110
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400.0       .01177      410.0       .01202      420.0       .01225      KAG  2400
430.0       .01250      440.0       .01275      450.0       .01297      KAG  2410
460.0       .01320      470.0       .01344      480.0       .01584      KAG  2420
570.0       .01584      1.        +51.        +5                        KAG  2430
400.0       .00698      410.0       .00712      420.0       .00745      KBG  2440
430.0       .00777      440.0       .00783      450.0       .00819      KBG  2450
460.0       .00840      470.0       .00854      480.0       .00868      KBG  2460
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+.100000E+06+.100000E+06                                                KBG  2500
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```
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400.0       .03445      410.0       .03505      420.0       .03568      VIAG2620
430.0       .03630      440.0       .03690      450.0       .03755      VIAG2630
460.0       .03819      470.0       .03910      480.0       .03940      VIAG2640
490.0       .04005      500.0       .04065      510.0       .04130      VIAG2650
520.0       .04190      530.0       .04255      540.0       .04315      VIAG2660
550.0       .04375      560.0       .04435      570.0       .04495      VIAG2670
1.        +.51.       +5                                                VIAG2680
400.0       .01900      410.0       .01940      420.0       .01990      VIRG2690
430.0       .02020      440.0       .02060      450.0       .02100      VIRG2700
460.0       .02145      470.0       .02180      480.0       .02215      VIRG2710
+.492000E+03+.212000E-01+.500000E+03+.224000E-01+.510000E+03+.237500E-01VIRG2720
+.520000E+03+.241000E-01+.530000E+03+.245000E-01+.540000E+03+.249000E-01VIRG2730
+.550000E+03+.253000E-01+.560000E+03+.257000E-01+.570000E+03+.262500E-01VIRG2740
+.100000E+06+.100000E+06                                                VIRG2750
+.492000E+03+.756000E+02+.530000E+03+.726000E+02+.550000E+03+.708000E+02SIG 2760
+.570000E+03+.690000E+02+.100000E+06+.100000E+06                        SIG 2770
```

APPENDIX E: SAMPLE INPUT DATA

```
APRIL 15, 1980    1           NOZZLE D, 2 MPA                      920     1
    1       0      0      30      30      30      1
-0.3         20.0            0.0              0.0              5.28
        .85E-60.C            -0.3             28.02            18.02           208.0
1010.0        0.05           290.0            537.0            537.0           20.0
20.0          0.005          0.005            0.0004           0.003           0.1
10 IN. NOZZLE
     .250001+03   .000000      .289564+03   .138144+00   .288580+03   .276288+00
     .286616+03   .414432+00   .283025+03   .552576+00   .276898+03   .690720+00
     .266595+03   .828864+00   .252206+03   .967008+00   .236879+03   .110515+01
     .222415+03   .124330+01   .208777+03   .138144+01   .195929+03   .151958+01
     .183834+03   .165773+01   .172458+03   .179587+01   .161766+03   .193402+01
     .151728+03   .207216+01   .142310+03   .221030+01   .133482+03   .234845+01
     .125216+03   .248659+01   .117431+03   .262474+01   .110251+03   .276289+01
     .103500+03   .290102+01   .972006+02   .303917+01   .913291+02   .317731+01
     .858612+02   .331546+01   .807742+02   .345360+01   .760453+02   .359174+01
     .716549+02   .372989+01   .675810+02   .386803+01   .639046+02   .400618+01
     .613069+02   .414432+01   .570700+02   .428246+01   .540765+02   .442061+01
     .513102+02   .455875+01   .487553+02   .469690+01   .463969+02   .483504+01
     .442206+02   .497319+01   .422129+02   .511133+01   .403611+02   .524947+01
     .386527+02   .538762+01   .370764+02   .552576+01   .356211+02   .566391+01
     .342765+02   .580205+01   .330328+02   .594019+01   .318810+02   .607834+01
     .308124+02   .621648+01   .298180+02   .635463+01   .288931+02   .649277+01
     .280280+02   .663091+01   .272169+02   .676906+01   .264540+02   .690720+01
     .257335+02   .704535+01   .250505+02   .718349+01   .244000+02   .732163+01
     .237779+02   .745978+01   .231803+02   .759792+01   .226035+02   .773607+01
     .220445+02   .787421+01   .215003+02   .801235+01   .209684+02   .815050+01
     .204466+02   .828864+01   .199329+02   .842679+01   .194257+02   .856493+01
     .189235+02   .870307+01   .184252+02   .884122+01   .179296+02   .897936+01
     .174360+02   .911751+01   .169438+02   .925565+01   .164525+02   .939379+01
     .159617+02   .953194+01   .154712+02   .967008+01   .149807+02   .980823+01
     .144904+02   .994637+01   .140000+02   .100845+02   .100000+06   .100000+06
```

APPENDIX F: SAMPLE 140PC CALIBRATION PROGRAM

```
10    DIM X(15,100),Sum(15),Mean(15),Sum2(15),Sd(15)
30    N=10
40    FOR I=1 TO N
50       OUTPUT 709;"AI1VT1"
60       ENTER 709:X(1,I)
70       OUTPUT 709;"AI2VT1"
80       ENTER 709:X(2,I)
90       OUTPUT 709;"AI3VT1"
100      ENTER 709:X(3,I)
110      OUTPUT 709;"AI4VT1"
120      ENTER 709;X(4,I)
130      OUTPUT 709;"AI5VT1"
140      ENTER 709:X(5,I)
150      OUTPUT 709;"AI6VT1"
160      ENTER 709:X(6,I)
170      OUTPUT 709;"AI7VT1"
180      ENTER 709:X(7,I)
190      OUTPUT 709;"AI8VT1"
200      ENTER 709:X(8,I)
210      OUTPUT 709;"AI9VT1"
220      ENTER 709:X(9,I)
230      OUTPUT 709;"AI16VT1"
240      ENTER 709:X(10,I)
250      OUTPUT 709;"AI11VT1"
260      ENTER 709:X(11,I)
261      OUTPUT 709;"AI12VT1"
262      ENTER 709:X(12,I)
263      OUTPUT 709;"AI13VT1"
264      ENTER 709:X(13,I)
267      OUTPUT 709;"AI17VT1"
268      ENTER 709;X(14,I)
270   NEXT I
```

```
280   PRINT "                         CHANNELS"
290   PRINT "    1        2        3        4        5        6        7        8"
300   !
310   PRINT "_____________________________________________________________________________
"
320   PRINT
330   FOR I=1 TO N
340      PRINT USING "DD.DDDD";X(1,I),X(2,I),X(3,I),X(4,I),X(5,I),X(6,I),X(7,I),
X(8,I)
350   NEXT I
360   PRINT
370   PRINT "                          CHANNEL"
380   PRINT "    9        10       11      12       13       17"
390   PRINT "_____________________________________________________________________________
"
400   FOR I=1 TO N
410      PRINT USING "DD.DDDD";X(9,I),X(10,I),X(11,I),X(12,I),X(13,I),X(14,I)
411   NEXT I
413   PRINT
414   PRINT "                               MEAN    ","          STANDARD DEVIATION"
415   PRINT "____________________________________________________________________"
420   PRINT
440   FOR J=1 TO 14
450      Sum(J)=0
460      FOR I=1 TO N
470         Sum(J)=Sum(J)+X(J,I)
480      NEXT I
490      Mean(J)=Sum(J)/N
510   NEXT J
512   FOR J=1 TO 14
513      FOR I=1 TO N
515        Sum2(J)=Sum2(J)+(X(J,I)-Mean(J))*(X(J,I)-Mean(J))
516      NEXT I
518      Sd(J)=SQR(Sum2(J)/(N-1))
519      IF J=14 THEN GOTO 523
521   PRINT "channel    ";J,Mean(J),"    ",Sd(J)
522   GOTO 525
523   PRINT "CHANNAL    ";J+3,Mean(J),"    ",Sd(J)
525   NEXT J
526   END
```

APPENDIX C: SAMPLE OUTPUT TO CALIBRATION PROGRAM

THIS DATA IS FOR A PRESSURE OF 0 PSI

CHANNELS 1	2	3	4	5	6	7	8
1.6588	1.8301	1.7702	1.6914	1.8429	1.7485	1.7900	1.8098
1.6589	1.8305	1.7705	1.6922	1.8431	1.7484	1.7901	1.8101
1.6598	1.8308	1.7715	1.6931	1.8446	1.7500	1.7918	1.8120
1.6605	1.8318	1.7717	1.6935	1.8444	1.7499	1.7916	1.8117
1.6603	1.8317	1.7722	1.6931	1.8446	1.7497	1.7917	1.8117
1.6598	1.8315	1.7716	1.6928	1.8439	1.7495	1.7909	1.8112
1.6596	1.8310	1.7712	1.6925	1.8437	1.7494	1.7909	1.8110
1.6597	1.8310	1.7714	1.6925	1.8441	1.7494	1.7910	1.8112
1.6593	1.8311	1.7712	1.6923	1.8438	1.7496	1.7907	1.8114
1.6594	1.8313	1.7709	1.6927	1.8438	1.7496	1.7906	1.8109

CHANNEL 9	10	11	12	13	17
1.7941	1.7381	1.7211	1.8335	-.0119	14.8960
1.7946	1.7389	1.7221	1.8336	-.0119	14.9000
1.7961	1.7397	1.7239	1.8353	-.0119	14.9090
1.7958	1.7400	1.7232	1.8341	-.0119	14.9060
1.7960	1.7401	1.7237	1.8351	-.0119	14.9030
1.7957	1.7402	1.7236	1.8347	-.0119	14.9000
1.7955	1.7388	1.7233	1.8340	-.0119	14.8990
1.7959	1.7394	1.7226	1.8342	-.0119	14.9020
1.7958	1.7398	1.7233	1.8338	-.0119	14.9020
1.7954	1.7394	1.7231	1.8341	-.0119	14.9000

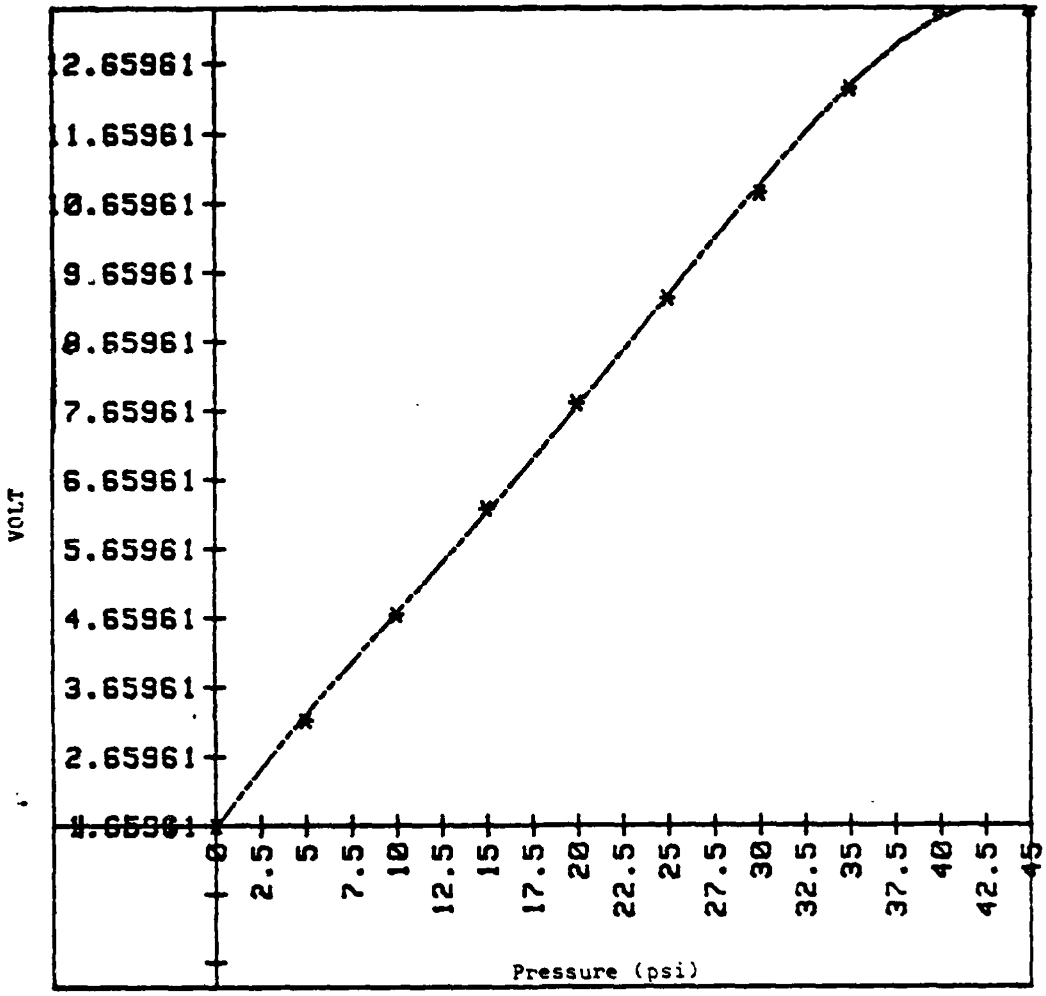
		MEAN	STANDARD DEVIATION
channel	1	1.65961	.000542524961023
channel	2	1.83108	.000528730134904
channel	3	1.77124	.000587272414548
channel	4	1.69261	.000583952052826
channel	5	1.84389	.000574359546703
channel	6	1.7494	.000537483849887
channel	7	1.79093	.0006254775953
channel	8	1.8111	.000697614984549
channel	9	1.79549	.000647130417905
channel	10	1.73944	.000668663675633
channel	11	1.72299	.000847807630172
channel	12	1.83424	.000607728009338
channel	13	-.0118729	8.1846740246E-6
channal	17	14.9017	.00368329562575

APPENDIX H: SAMPLE 200PC CALIBRATION PROGRAM

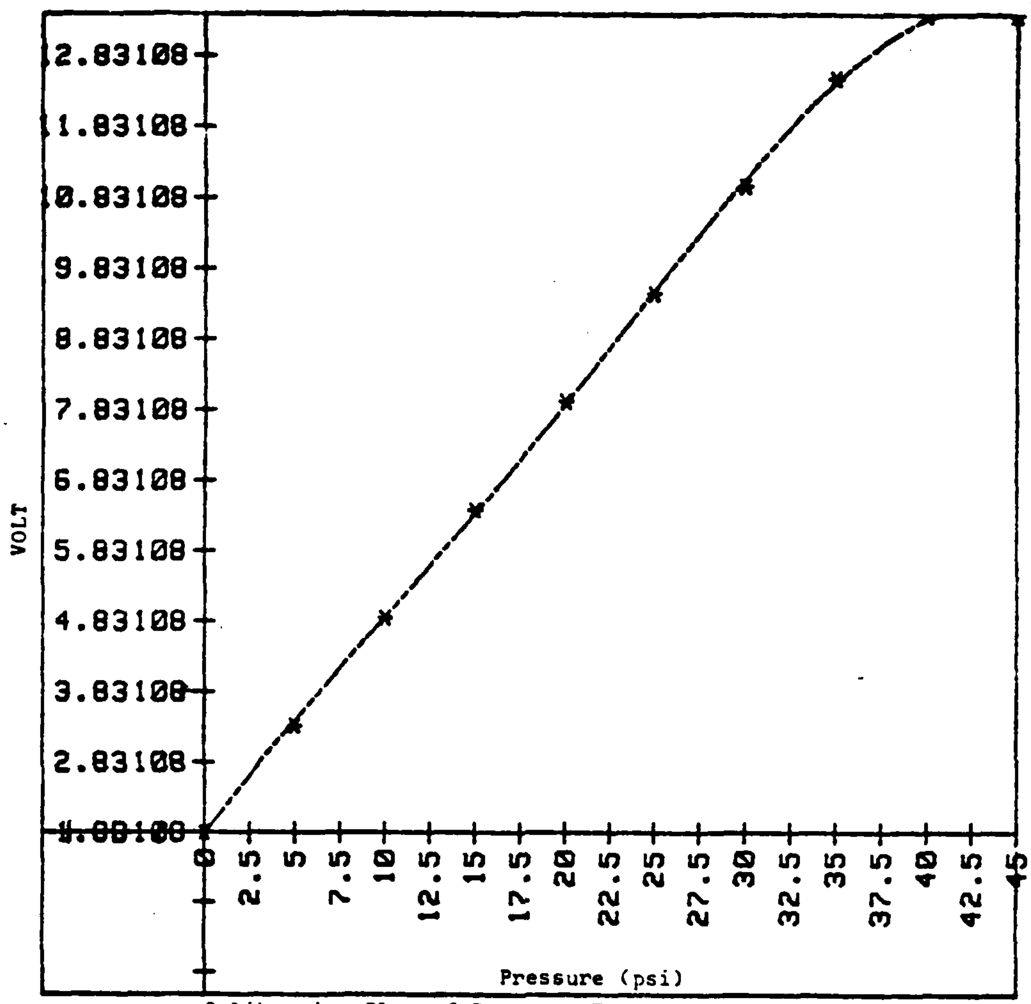
```
PRINT "THIS PROGRAM IS USED TO CALIBRATE 100 PSI PRESSURE TRANSDUCERS."
PRINT "ENTER THE AMOUNT OF READINGS YOU WISH THE PROGRAM TO AVERAGE"
DIM X(11,100),Sum(11),Mean(11),Sum2(11),Sd(11)
PRINT
INPUT N
Y=0
FOR T=1 TO 11
  PRINT
  PRINT
  PRINT "THIS RUN IS FOR A PRESSURE OF";Y;"PSI"
  PRINT "____________________________________"
  PRINT
  PRINT " ONCE THE PRESSURE IS SET AT";Y;"PSI"
  PRINT "PUSH THE CONTINUE BUTTON AND WAIT FOR DATA."
  Y=Y+10
  PAUSE
FOR I=1 TO N
   OUTPUT 709;"AI12VT1"
   ENTER 709;X(1,I)
   OUTPUT 709;"AI14VT1"
   ENTER 709;X(2,I)
   OUTPUT 709;"AI15VT1"
   ENTER 709;X(3,I)
NEXT I
```

```
PRINT "                        CHANNELS"
PRINT "     1,       2        3  "
PRINT "__________________________________________________________________"
PRINT
FOR I=1 TO N
   PRINT USING "DD.DDDD";X(1,I),X(2,I),X(3,I)
NEXT I
PRINT
PRINT "                              MEAN   ","        STANDARD DEVIATION"
PRINT "______________________________________________________________________________"
PRINT
FOR J=1 TO 3
   Sum(J)=0
   FOR I=1 TO N
      Sum(J)=Sum(J)+X(J,I)
   NEXT I
   Mean(J)=Sum(J)/N
NEXT J
FOR J=1 TO 3
   FOR I=1 TO N
     Sum2(J)=Sum2(J)+(X(J,I)-Mean(J))*(X(J,I)-Mean(J))
   NEXT I
   Sd(J)=SQR(Sum2(J)/(N-1))
PRINT "channel   ";J,Mean(J),"    ",Sd(J)
NEXT J
PRINT
PRINT
PRINT
NEXT T
END
```

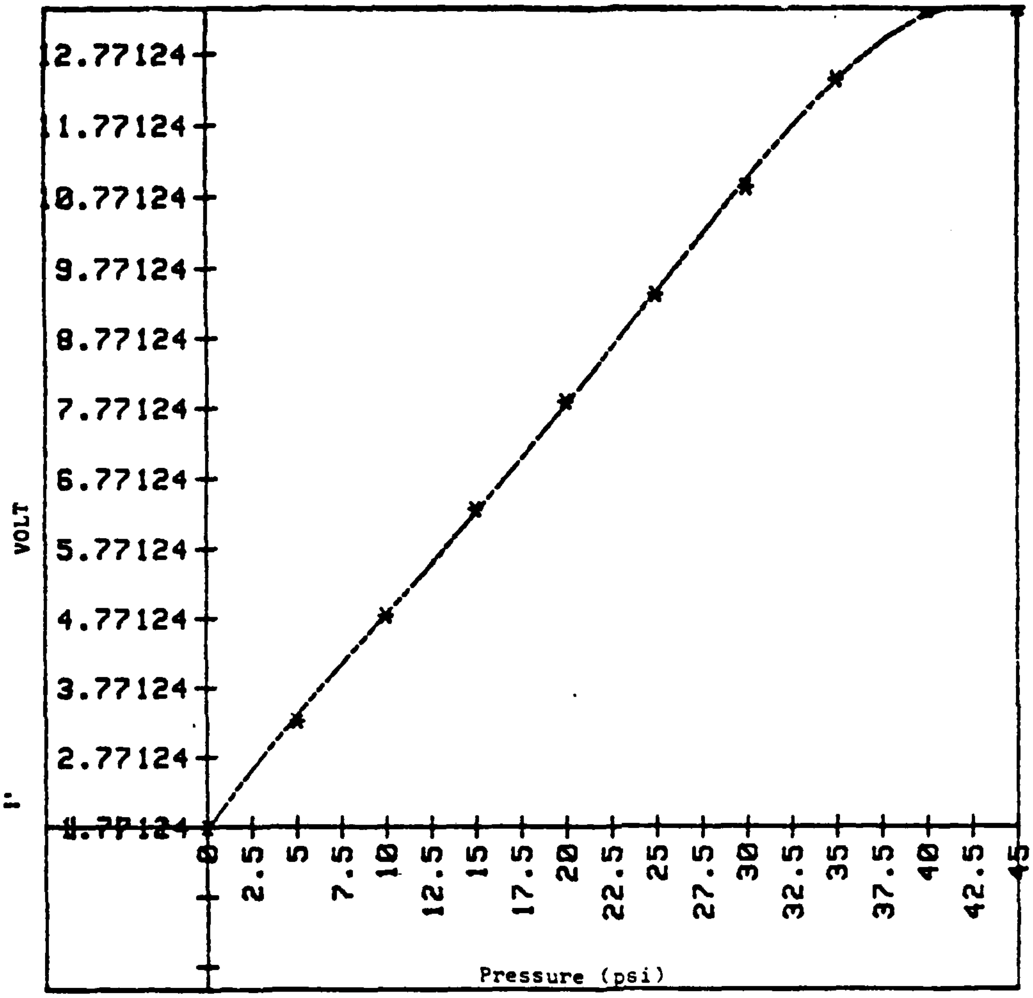
APPENDIX I: CALIBRATION PLOT OF PRESSURE TRANSDUCERS



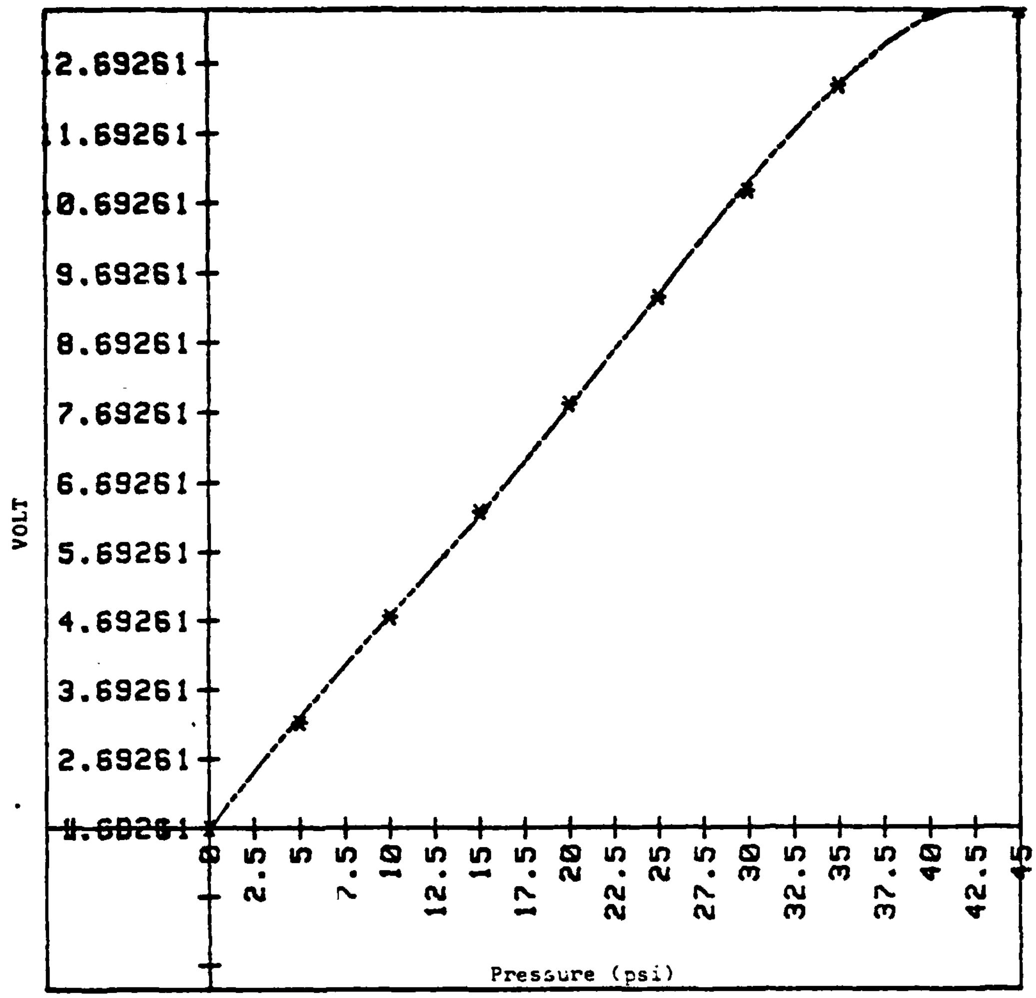
Calibration Plot of Pressure Transducer A



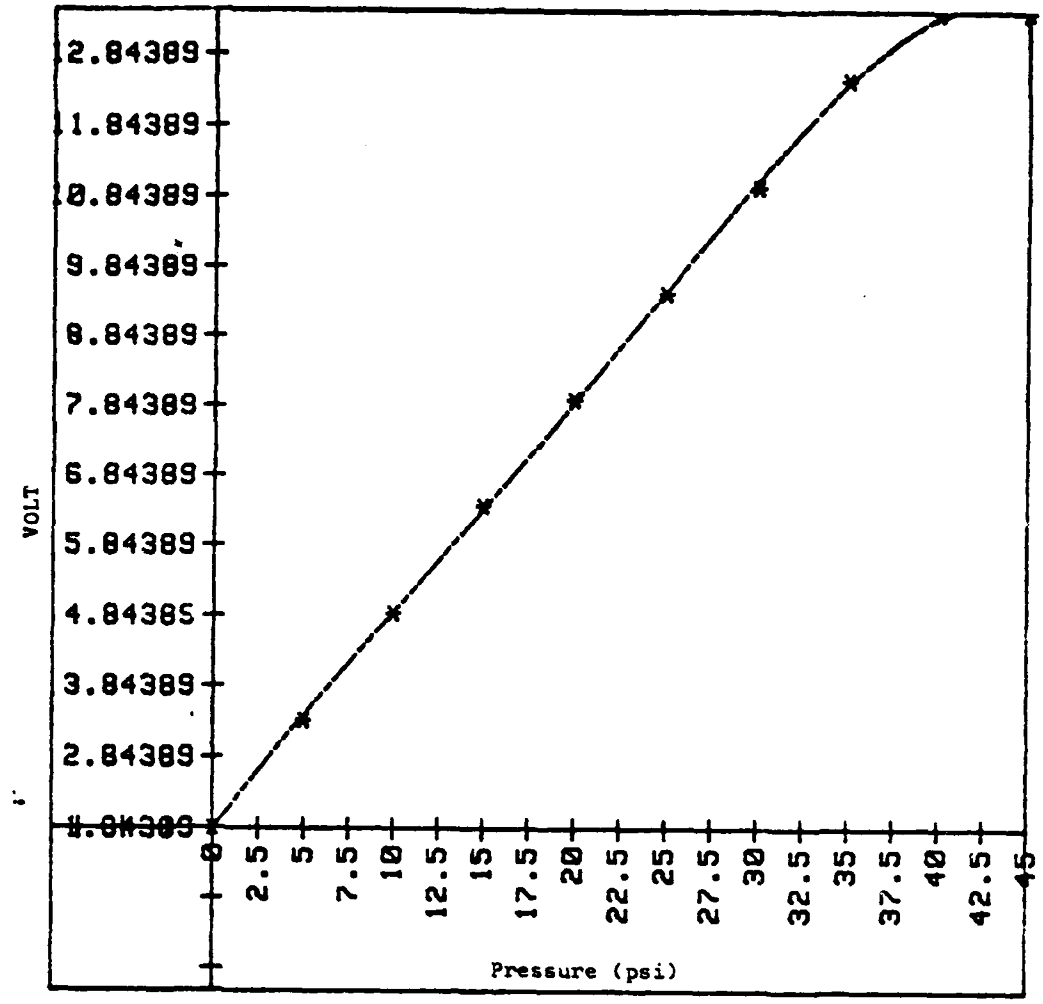
Calibration Plot of Pressure Transducer B



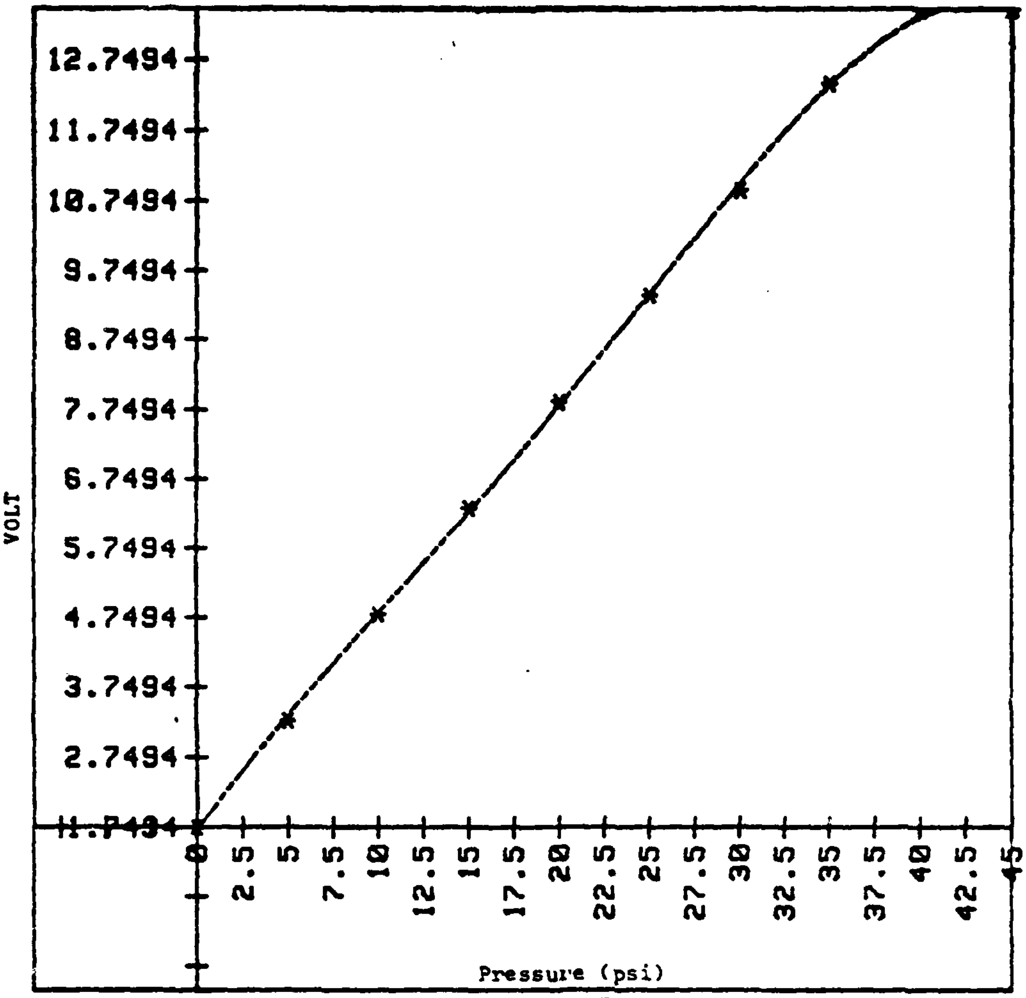
Calibration Plot of Pressure Transducer C



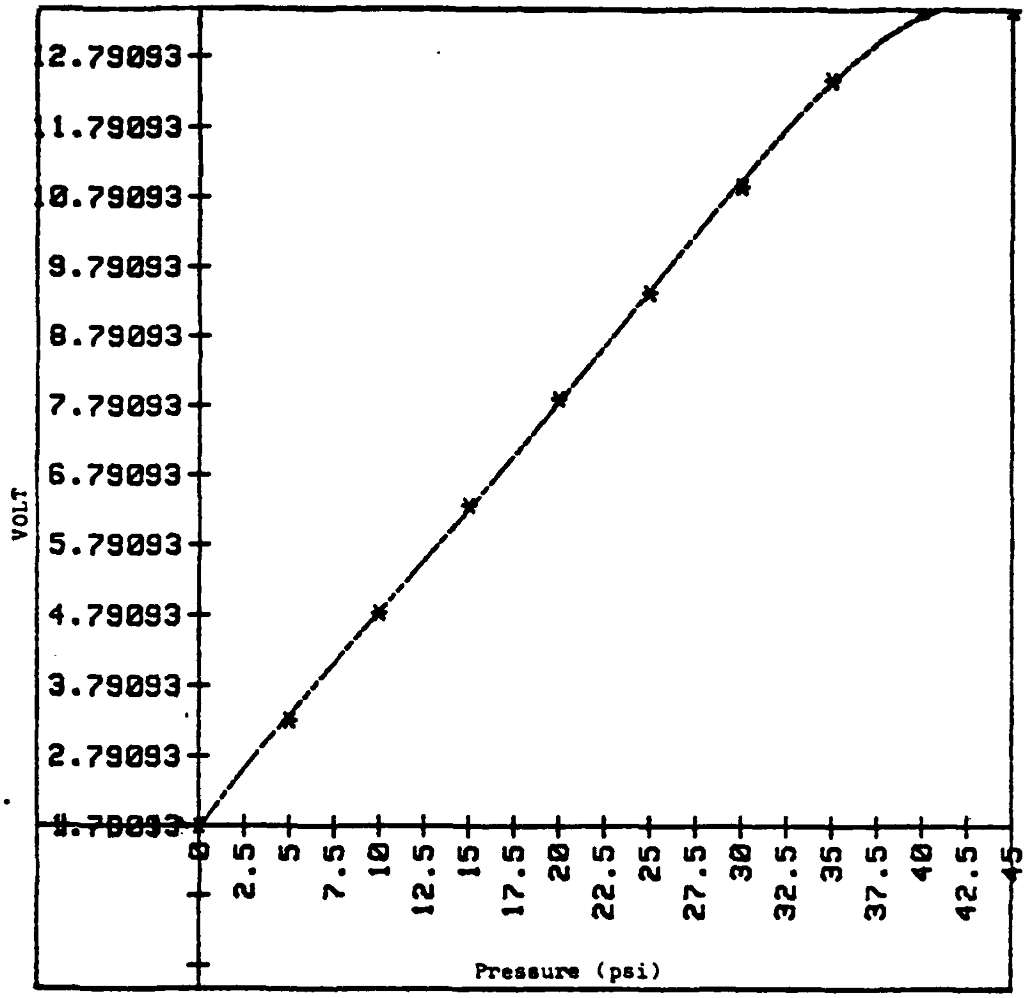
Calibration Plot of Pressure Transducer D



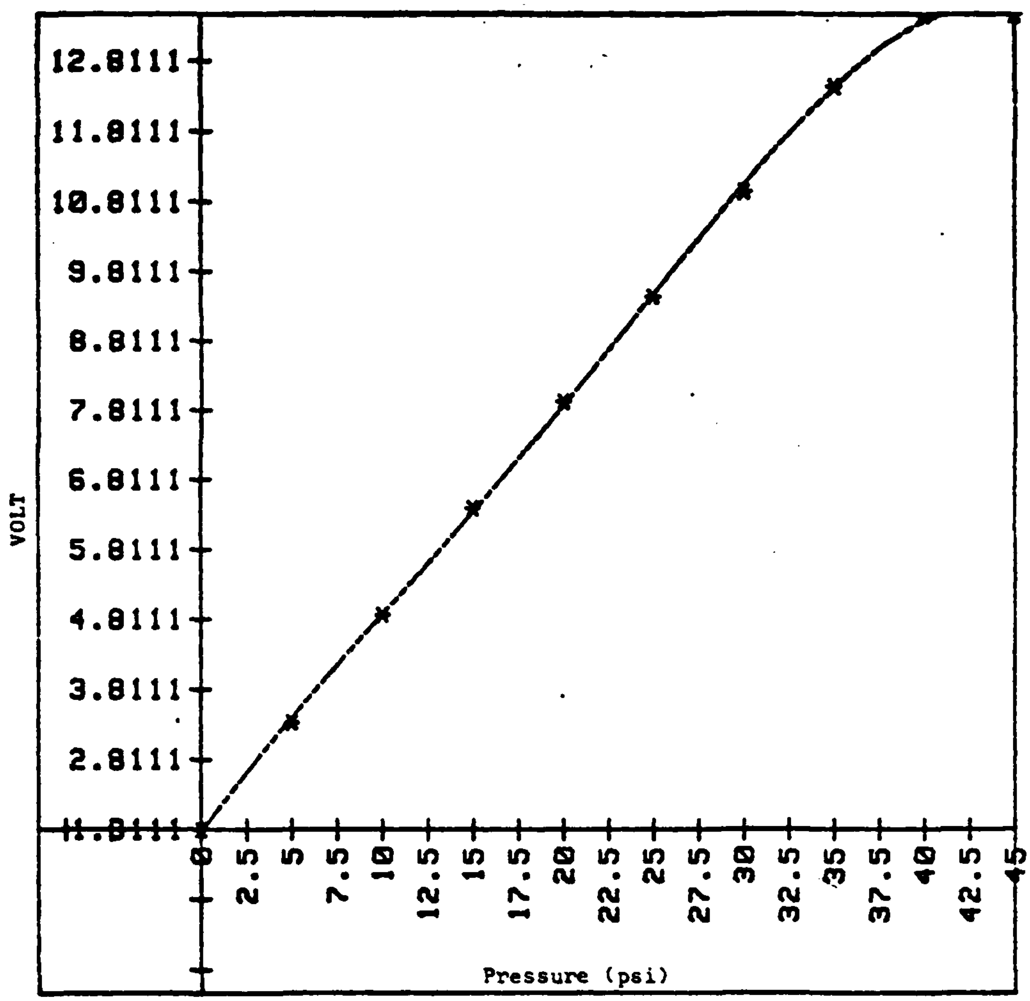
Calibration Plot of Pressure Transducer E



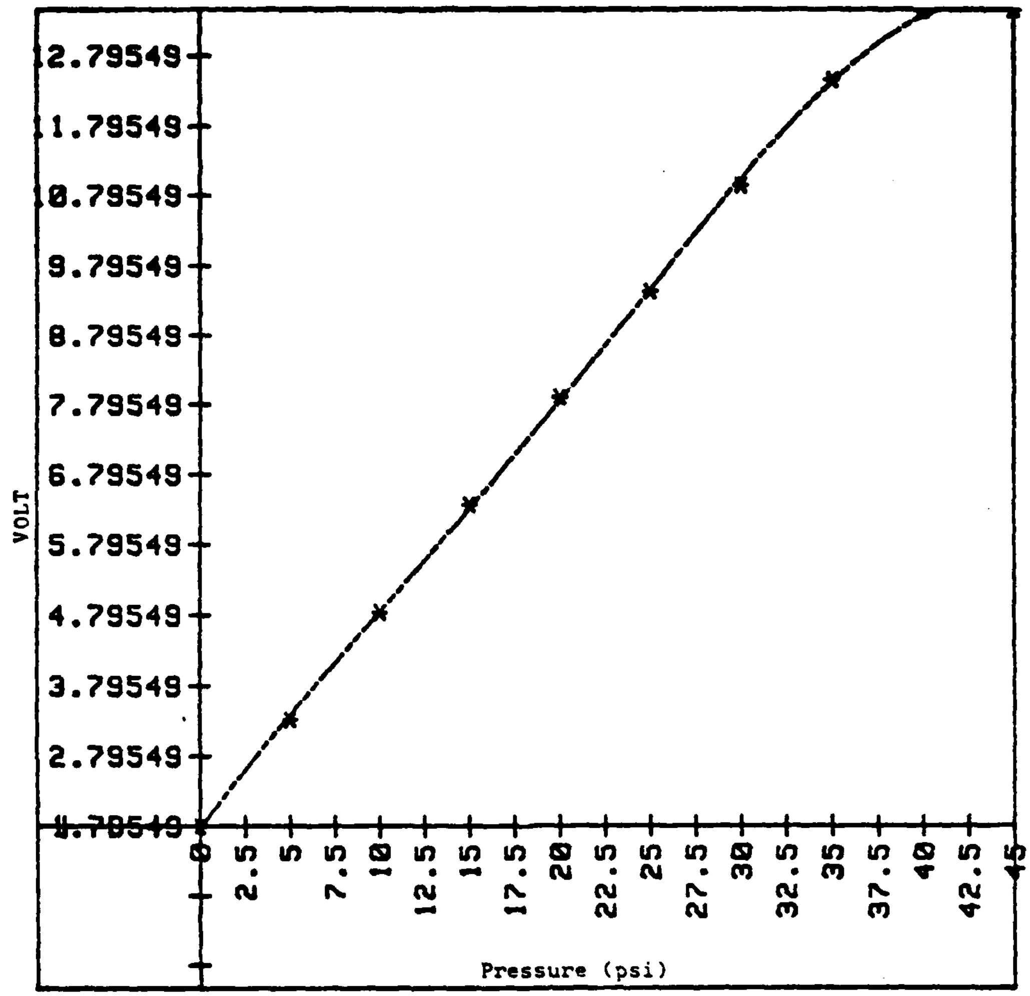
Calibration Plot of Pressure Transducer F



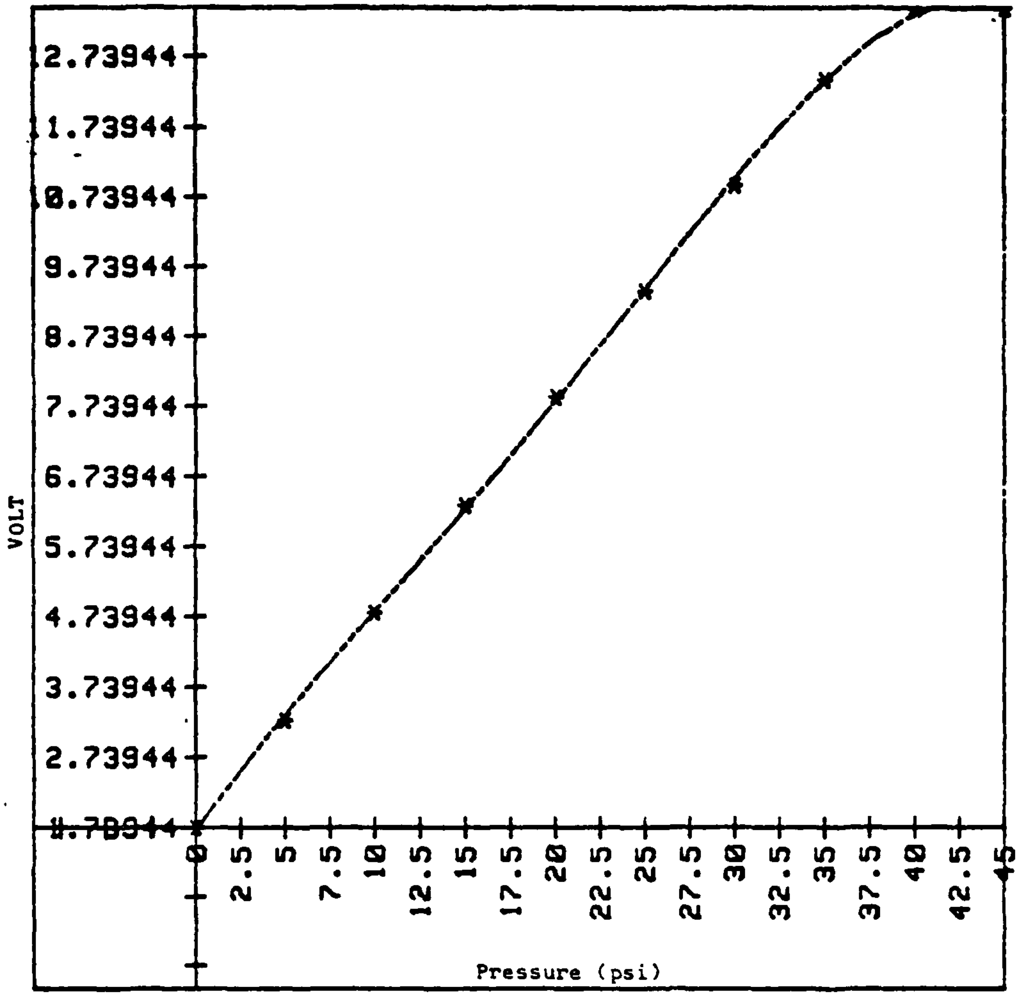
Calibration Plot of Pressure Transducer G



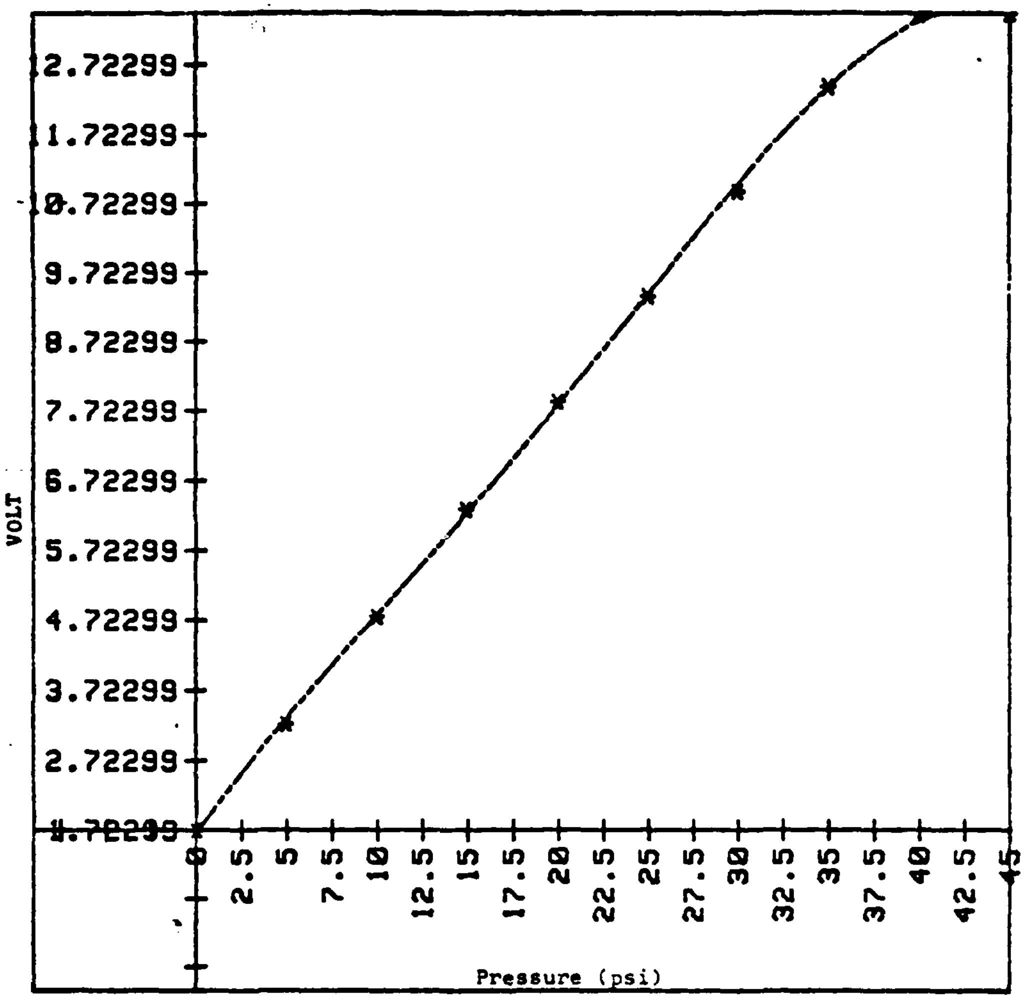
Calibration Plot of Pressure Transducer H



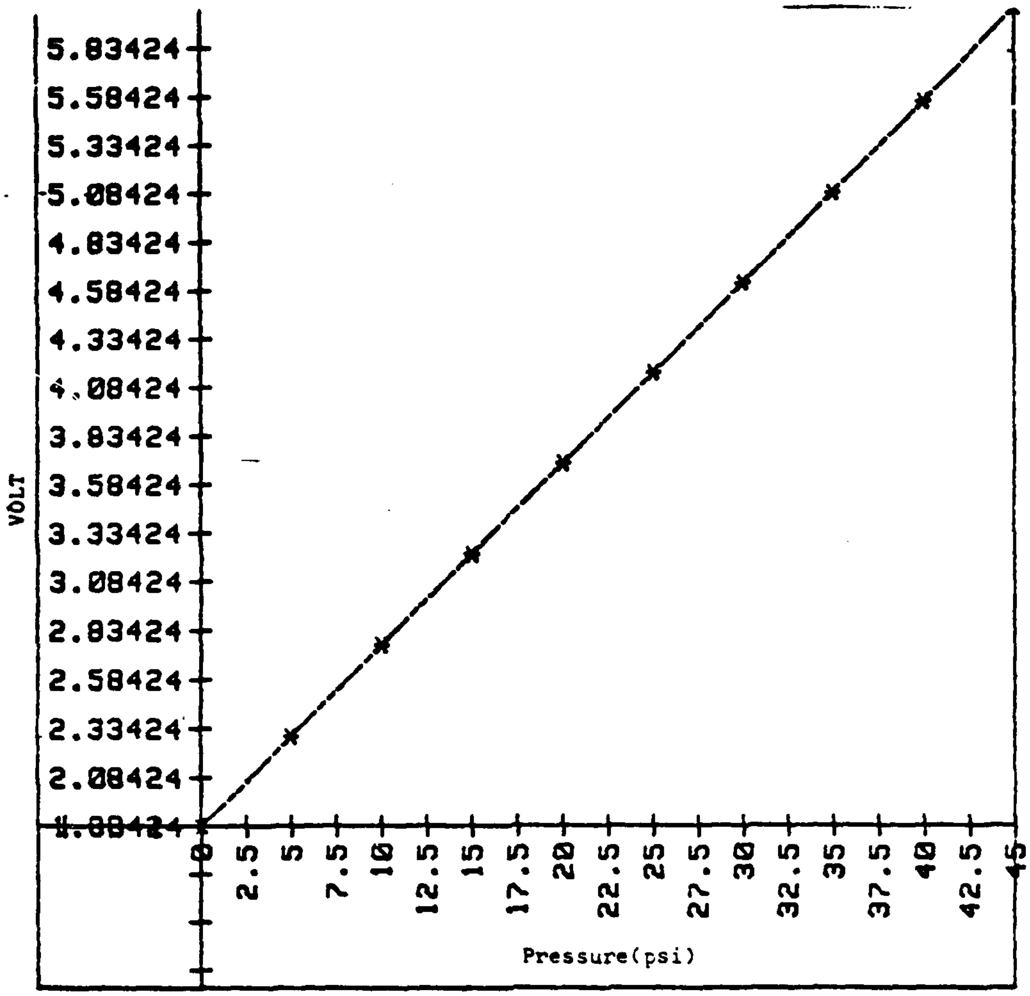
Calibration Plot of Pressure Transducer I



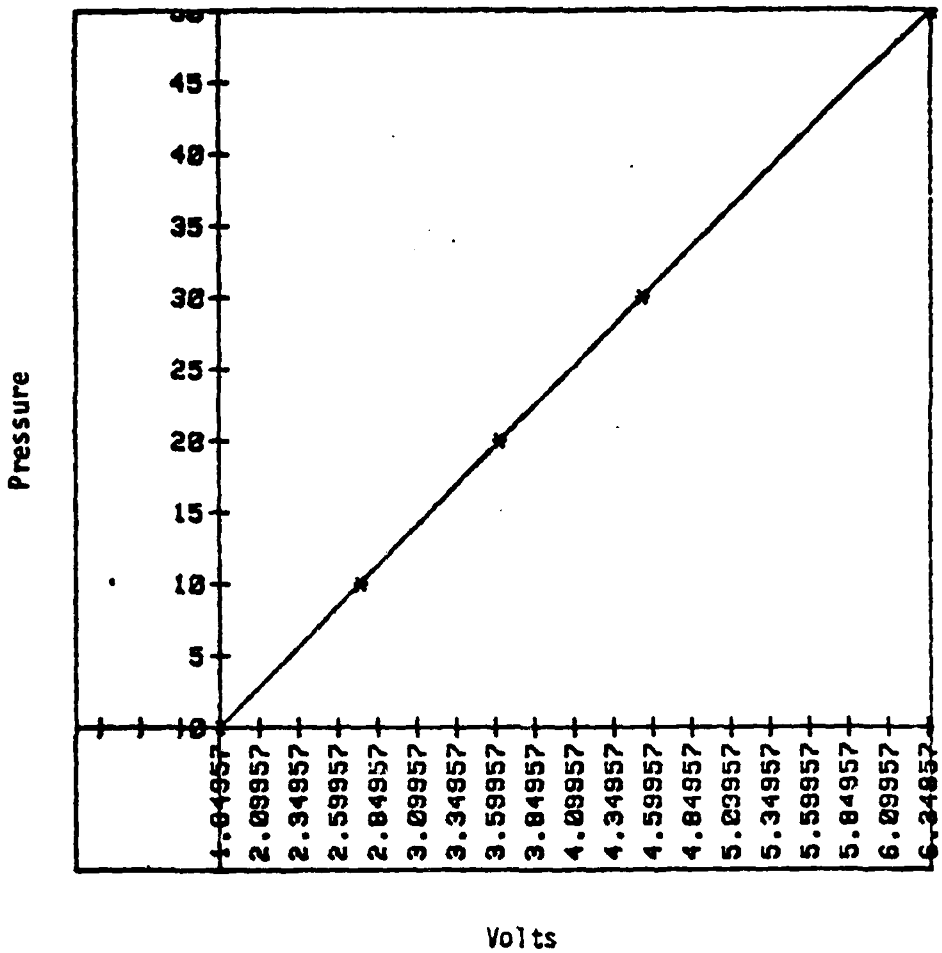
Calibration Plot of Pressure Transducer J



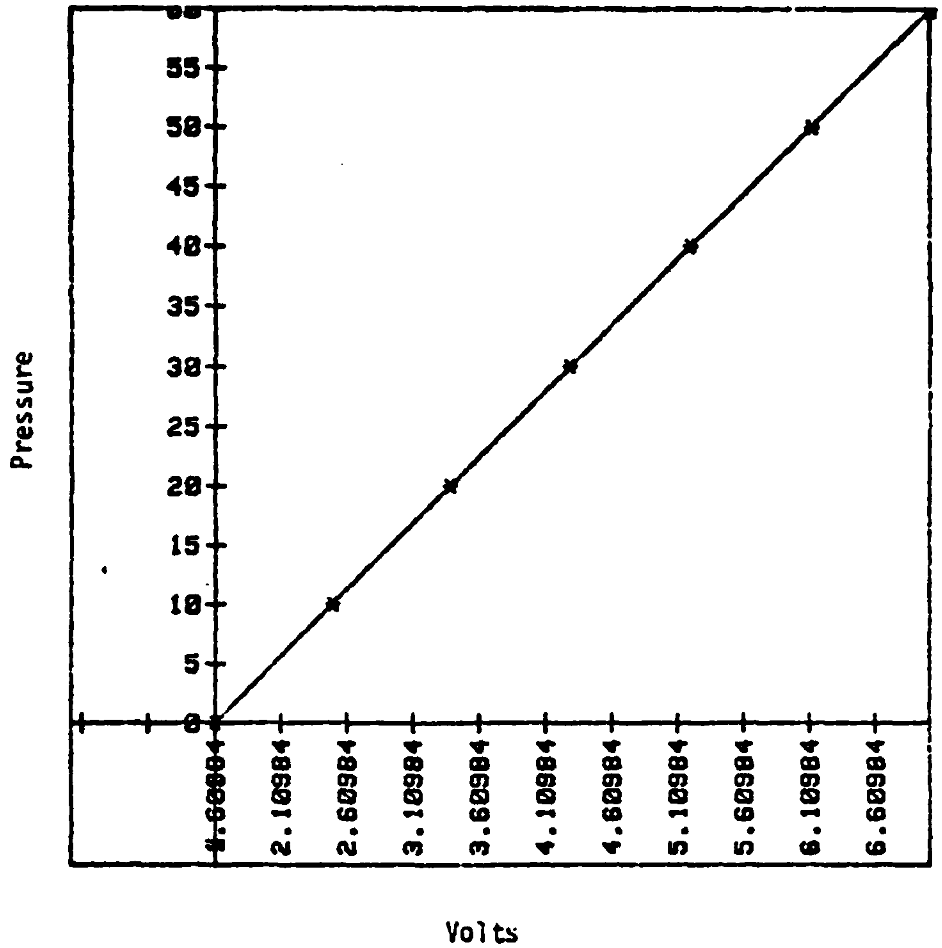
Calibration Plot of Pressure Transducer K



Calibration Plot of Pressure Transducer L

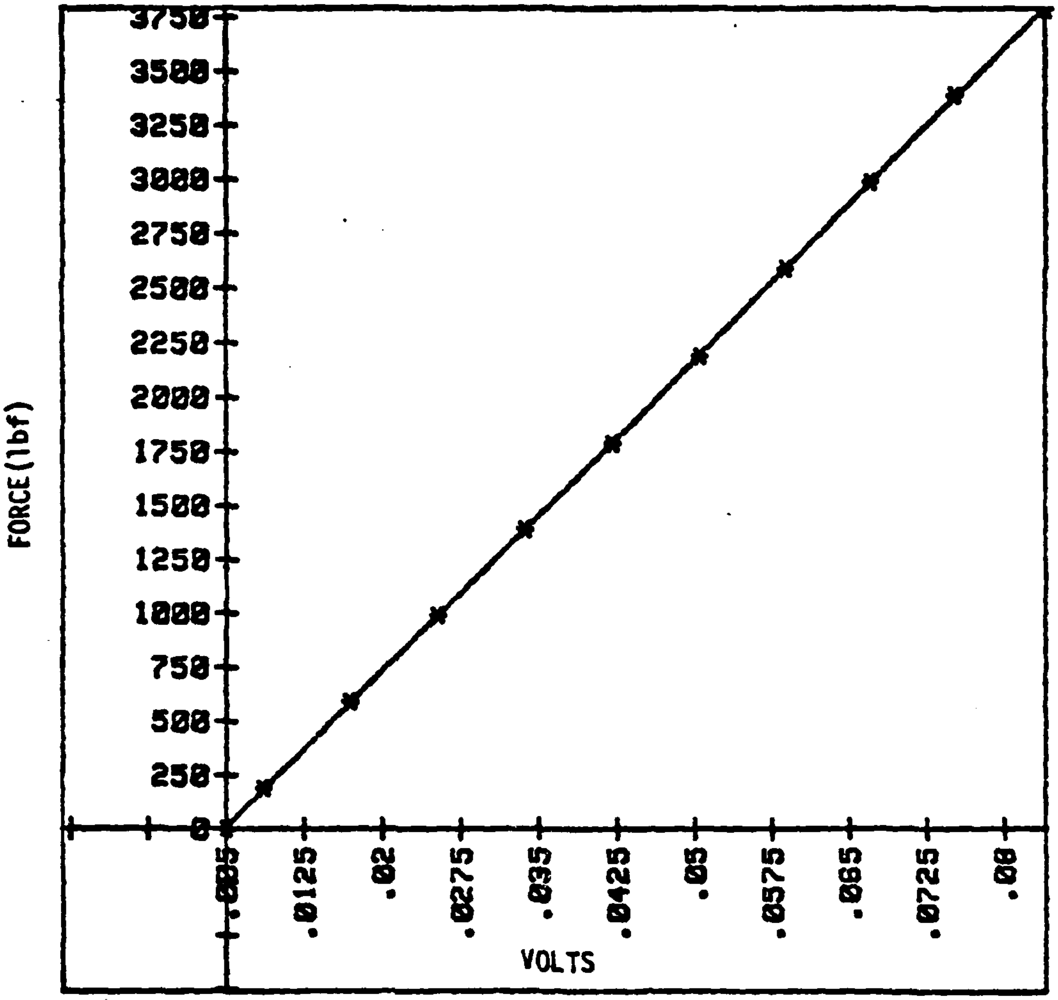


Calibration plot of pressure Transducer 0



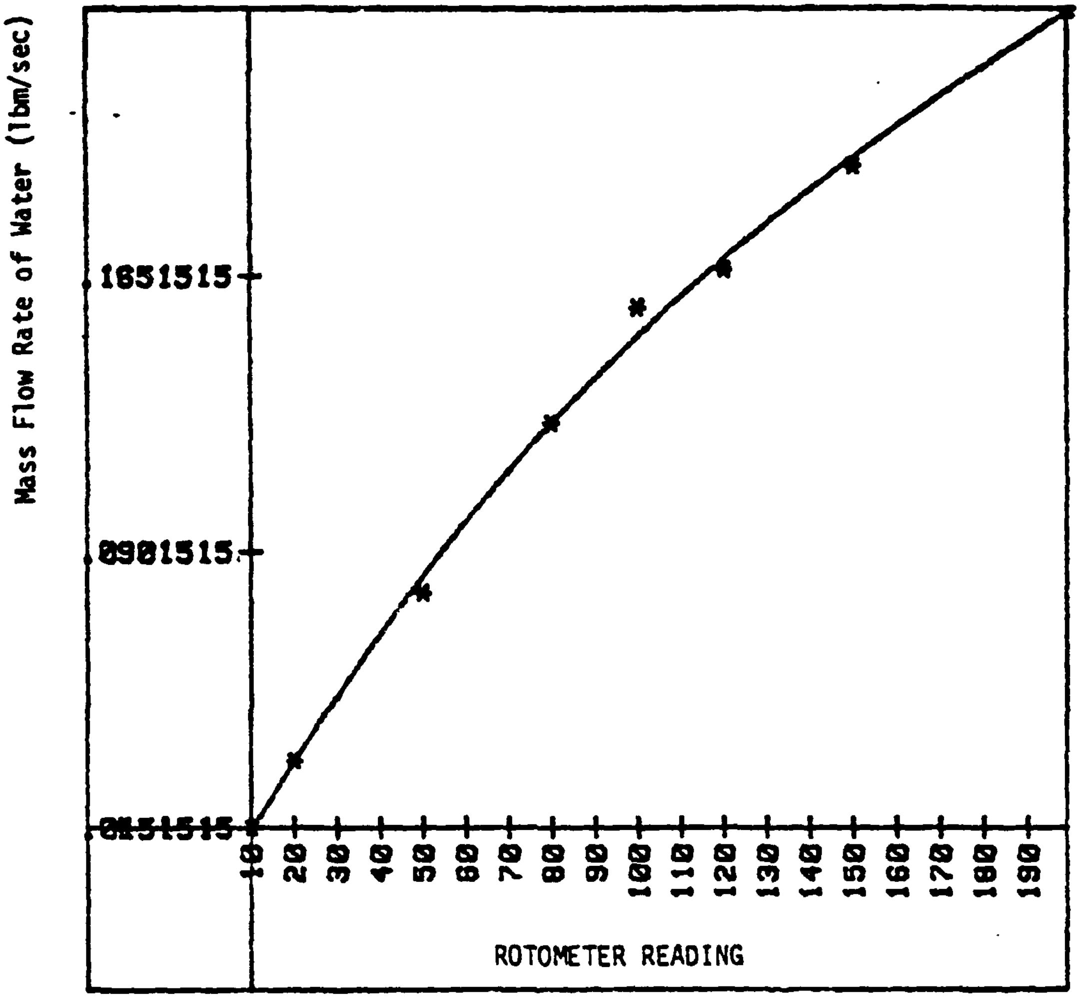
Calibration Plot of Pressure Transducer P

APPENDIX J: CALIBRATION PLOT FOR FORCE-BLOCK



Calibration Plot For Force-Block

APPENDIX K: CALIBRATION PLOT FOR ROTOMETER



Calibration Plot for Rotometer

APPENDIX L: DATA ACQUISITION AND ANALYSIS PROGRAM

```
3      PRINT "INPUT ROTOMETER READING"
4      INPUT Rr
5      PRINT Rr
7      DIM A(14),B(14),C(14),Dist(14),D(14)
8      DIM Press(14)
10     DIM X(18,100),Sum(18),Mean(18),Sum2(18)
30     N=10
40     FOR I=1 TO N
50         OUTPUT 709;"AI1VT1"
60         ENTER 709:X(1,I)
70         OUTPUT 709;"AI2VT1"
80         ENTER 709:X(2,I)
90         OUTPUT 709:"AI3VT1"
100        ENTER 709:X(3,I)
110        OUTPUT 709:"AI4VT1"
120        ENTER 709:X(4,I)
130        OUTPUT 709:"AI5VT1"
140        ENTER 709:X(5,I)
150        OUTPUT 709:"AI6VT1"
160        ENTER 709:X(6,I)
170        OUTPUT 709:"AI7VT1"
180        ENTER 709:X(7,I)
190        OUTPUT 709:"AI8VT1"
200        ENTER 709:X(8,I)
210        OUTPUT 709;"AI9VT1"
220        ENTER 709;X(9,I)
230        OUTPUT 709:"AI10VT1"
240        ENTER 709:X(10,I)
250        OUTPUT 709;"AI11VT1"
260        ENTER 709:X(11,I)
261        OUTPUT 709;"AI12VT1"
262        ENTER 709:X(12,I)
263        OUTPUT 709;"AI13VT1)"
264        ENTER 709:X(13,I)
265        OUTPUT 709;"AI14VT1)"
266        ENTER 709:X(14,I)
267        OUTPUT 709:"AI15VT1)"
268        ENTER 709;X(15,I)
270    NEXT I
440    FOR J=1 TO 16
450        Sum(J)=0
460        FOR I=1 TO N
470            Sum(J)=Sum(J)+X(J,I)
480        NEXT I
490        Mean(J)=Sum(J)/N
510    NEXT J
```

```
520   FOR I=1 TO 14
530   READ A(I),B(I),C(I),D(I),Dist(I)
540   DATA -6.049177,3.92598,-.17336131,.0112105,.5
550   DATA -7.059265,4.233834,-.2292065,.01415403,1.5
560   DATA -6.4905288,3.93412037,-.160249802,.009448598,2.5
570   DATA -7.05653853,4.69207328,-.341175732,.0189756532,3.5
580   DATA -7.00950749,4.15163753,-.207173977,.0123697788,4.5
590   DATA -6.38855694,3.93348997,-.160546739,.0095126941,5.5
600   DATA -6.58938462,3.95696947,-.164270383,.0096133938,6.5
610   DATA -6.587731,3.90750953,-.158062598,.0094269372,7.5
620   DATA -6.59491204,3.94889685,-.162699726,.009565139,8.5
630   DATA -6.35328646,3.92659595,-.165085722,.0099773509,9.5
640   DATA -6.20324295,3.84628939,-.146968664,.0088046866,10.5
650   DATA -20.2065629,11.1571691,-.0859126,.004917379,0
660   DATA -20.6682414,11.0677155,-.07562378,.011185984,0
670   DATA -18.8267355,11.9281137,-.17715903,.011005888,0
680   Press(I)=A(I)+B(I)*Mean(I)+C(I)*Mean(I)^2+D(I)*Mean(I)^3
681   Press(I)=Press(I)+14.696
690   NEXT I
```

```
700   Fb=1/453.6*(-234.396482+48715.7753*Mean(15)-11261.538*Mean(15)^2+33899.3*M
ean(15)^3)
710   Mwater=-.0063268+.002097278*Rr-.00000658*Rr^2+.000000011*Rr^3
720   Fn=Fb*22.5/22.0
730   Dw=.920/12
740   Dd=3/12
750   E=1/(1-Dw/Dd)
760   Dp=Mean(14)-Mean(13)
770   Cc=.62
771   K=Cc*E
772   Aa=3.1416*Dw^2/4
774   Y=1-(.41+.35*(Dw/Dd)^4*(Dp/(1.4*Mean(14))))
780   Gc=32.2
790   Den=.076297*Mean(12)/14.696
800   Mair=K*Aa*Y*SQR(2*Gc*Den*Dp*144)
810   Mtotal=Mair+Mwater
820   Vexit=Fn/(Mtotal)*32.2
830   PRINT
840   PRINT "PRESSURE AS A FUNCTION OF DISTANCE"
850   PRINT "____________________________________"
860   PRINT "DISTANCE(X)","PRESSURE"
870   PRINT "_______________________"
880   FOR I=1 TO 14
890   PRINT Dist(I),Press(I)
900   NEXT I
910   PRINT "MASS FLOW RATE OF WATER =";Mwater;"LBM/SEC"
920   PRINT "MASS FLOW RATE OF AIR   =";Mair;"LBM/SEC"
930   PRINT "TOTAL MASS FLOW RATE    =";Mtotal;"LBM/SEC"
940   PRINT "THRUST                  =";Fn;"LBF"
950   PRINT "MIXTURE RATIO           =";Mwater/Mair
960   PRINT "EXIT VELOCITY           =";Vexit;"FT/SEC"
970   PRINT "INLET PRESSURE          =";Press(12);"PSI"
980   END
```

INPUT ROTOMETER READING
 0

PRESSURE AS A FUNCTION OF DISTANCE

DISTANCE(X)	PRESSURE
.5	14.5598137417
1.5	14.4607948757
2.5	14.4788575371
3.5	14.4188520649
4.5	14.4711792506
5.5	14.5553698274
6.5	14.4532490549
7.5	14.4461409662
8.5	14.5336111051
9.5	14.5262956477
10.5	14.5245848183
0	14.1098474897
0	11.8981971096
0	17.6235437008

MASS FLOW RATE OF WATER =-.0063268 LBM/SEC
MASS FLOW RATE OF AIR = .0110711550501 LBM/SEC
TOTAL MASS FLOW RATE = .00474435505015 LBM/SEC
THRUST = 1.76920486692 LBF
MIXTURE RATIO =-.571467021403
EXIT VELOCITY = 12007.6166544 FT/SEC
INLET PRESSURE = 14.1098474897 PSI

APPEND'X M: DUAL-PHASE TWO-COMPONENT COMPUTER PROGRAM

```
$JOB
C*****************************************************************
C     REAL TWO-PHASE TWO-COMPONENT NOZZLE FLOW                    *   MAIN0010
C     MODIFIED FOR USE AT NAVAL POSTGRADUATE SCHOOL               *   MAIN0150
C     PROF. J.SLADKY AND  LT. T.C.HOLLIS                          *   MAIN0190
C*****************************************************************
      COMMON TZZZAY                                                   MAIN0190
      DIMENSION TZZZAY(11200)                                         MAIN0210
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP          MAIN0220
C     IT MUST BE THE FIRST COMMON BLOCK                               MAIN0230
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMO  ,
     1          ALPHS   , AM      , AP      , AS      , AT      , BA      ,  MAIN0250
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,  MAIN0260
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,  MAIN0270
     4 CBG1   , CAL     , CASE    , CCTMB   , CBG     , CBLMB   , COL     ,  MAIN0280
      COMMON    CONT    , CDP     , CD      , CFIM    , CFIMS   , CFOM    ,  MAIN0290
     6          CFOMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM     ,  MAIN0300
     7          CLMS    , CSAVE   , D       , D2      , DA      , DATE    ,  MAIN0310
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    ,  MAIN0320
     9          DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2   ,  MAIN0330
      COMMON    DEMAGB  , DEMAG   , DEMBGB  , DEMBG   , DEMGB   , DINT    ,  MAIN0340
     1          DLGIS   , DLGOS   , DO      , DP1     , DP      , DRAY    ,  MAIN0350
     2          DPT     , DRO     , DR      , DS1     , DSAVE   , DSLIM   ,  MAIN0360
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  ,  MAIN0370
     4          DSRPS   , DS      , DSX1    , DSY2    , DTG1    , DTGJ    ,  MAIN0380
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLJ    , DTL     ,  MAIN0390
     5          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DY      , DYL     ,  MAIN0400
     7          DYO     , EB      , EDS     , EMAGB   , EMAG    , EMLGB   ,  MAIN0410
     8          EMBG    , EMGB    , EMG     , EMGS    , EMLB    , EMLS    ,  MAIN0420
     9          EML     , EMLS    , EMT     , ESO     , FLESP   , FUN     ,  MAIN0430
      COMMON    H       , HJI     , HKAG    , HKGS    , HKGM1   , HKGM2   ,  MAIN0440
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    ,  MAIN0450
     2          HLB1    , HLBM    , HLB     , HLBS    , HM      , HMS     ,  MAIN0460
     3          HOPE    , HT      , IACT    , IBLM    , IBLX    , IBM     ,  MAIN0470
     4          IJH     , INT     , ISET    , IZERO   , K       , K1      ,  MAIN0480
      COMMON    K2      , KAD     , KDSCT   , KDS     , KL      , KG1     ,  MAIN0490
     6          KT      , KIDCT   , KTB     , KXP1    , KXP     , L       ,  MAIN0500
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPGCT   ,  MAIN0510
     8          LGM     , MBU     , MFFO    , MFP     , MGEO    , MM      ,  MAIN0520
     9 B      , MOP     , MTHI    , NACV    , NB      , NCLK    , NCPS    ,  MAIN0530
      COMMON    NDIAG   , NGS     , NGS     , NIB     , NIS     , NEST    ,  MAIN0540
     1          NNA     , NNB     , NNDS    , NNN     , NNO     , NN      ,  MAIN0550
     2          NNSOO   , NNSO    , NNS     , NP      , NZO     , NS      ,  MAIN0560
     3          P       , P10     , P11     , PAB     , PAMB    , PA      ,  MAIN0570
     4          PAS     , PBB     , PBMB    , PROB    , PBO     , PB      ,  MAIN0580
      COMMON    PBS     , PHIAD   , PHIGA   , PHI     , PINT    , PL      ,  MAIN0590
     6          PLT     , PO      , PS      , PT      , Q       , QID     ,  MAIN0600
     7          R1      , RA      , RAG     , RAXO    , RAX     , RB      ,  MAIN0610
     8          RC      , RDELIM  , RDTIOM  , RDIMS   , RDOMS   , RFF     ,  MAIN0620
     9          REM     , REMS    , RDLIM   , RHOD    , RHOZ    , RHOGB   ,  MAIN0630
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   ,  MAIN0640
     1          RIM     , RI      , RM      , ROALB   , RIAL    , RILB    ,  MAIN0650
     2          ROIL    , ROM     , RO      , R       , RSLIM   , RT      ,  MAIN0660
     3          RVG     , RV      , RVS     , S       , S1      , S2      ,  MAIN0670
     4          S1      , S4      , SA      , SB      , SGN     , SIG     ,  MAIN0680
      COMMON    SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,  MAIN0690
     6          SMLS    , SMLP    , SMLG    , SM      , SOJ1    , SOJ2    ,  MAIN0700
     7          SOP     , SO      , SOLM    , SS      , SSM     , SSN     ,  MAIN0710
     8          T       , T3      , TDRAY   , TDRAY1  , TEMO    , TEP     ,  MAIN0720
     9          TG      , TGS     , TMIM    , TMID    , TMT     , THIS    ,  MAIN0730
      COMBON    THOM    , THOO    , THO     , THOS    , TI      , TIP     ,  MAIN0740
     1          TLMB    , TLM     , TL      , TLS     , TOT     , TWIN    ,  MAIN0750
     2          TWINS   , TWOM    , TWOMS   , V1      , V2      , VAG     ,  MAIN0760
     3          VBO     , VBOS    , VBX     , VBMSQ   , V3      , VBIO    ,  MAIN0770
     4          VGS     , VGO     , VG      , VGSQ    , VGS     , VIAG    ,  MAIN0780
      COMMON    VIALB   , VIAL    , VIBG    , VIGLB   , VIBL    , VIGM    ,  MAIN0790
     6          VIGMS   , VILB    , VILB    , VILMS   , VLM     , VLO     ,  MAIN0800
     7          VL      , VLSO    , VLS     , VS      , VSS     , WAGB    ,  MAIN0810
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,  MAIN0820
     9          WBL     , WGB     , WG      , WGS     , WIM     , WIMS    ,  MAIN0830
      COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLK    ,  MAIN0840
     1          XINT    , XP      , XS      , XX      , XXA     , XI      ,  MAIN0850
```

```
     2           YIS      , YO       , YOS      , ZZZ      , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),OID(8),XP(2,75),PL1(10),
     1     C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TDRAY(100),TDRAY
     21(100),DRAY(75),HT(8),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      XX=-1.0
      SMIN = 1.0E-6
      IZERO = 0
      ISET = 75
      DINT(1)=.5
      DINT(2)=.1
      DINT(3)=.01
      DINT(4)=.001
      DINT(5)=.0001
      DINT(6)=.00001
      DINT(7)=.000001
      DINT(8)=.0000001
      CALL ADATA
C
C INITIALIZE TABLE TAPE, BRING IN PERMANENT TABLES (ONE-DIMENSIONAL),
C    FILL ARRAY INDICATING TEMPERATURES INCLUDED IN TWO
C    DIMENSIONAL TABLES, INITIALIZE PAGE COUNT.
C
    5 LPGCT=1
      CALL TABLE
      CALL INTEP(VAR,0,T,P)
C     ACTIVATE THE FOLLOWING CARD TO GET A PRINTOUT OF THE PROPERTIES
C     CALL INTEP(VAR,20,T,P)
      NSTMT=1999
  100 CONTINUE
      CALL SECT1
      IF(NSTMT-5)999,5,101
  101 CONTINUE
      IF(NSTMT-99) 999,99,200
  999 CALL DUMP
  200 CONTINUE
      CALL SECT2
      IF(NSTMT-40) 999,300,201
  201 IF(NSTMT-50) 999,300,202
  202 IF(NSTMT-60) 999,400,203
  203 IF(NSTMT-110) 999,700,999
  300 CONTINUE
      CALL SECT3
      IF(NSTMT-30) 999,200,301
  301 IF(NSTMT-70) 999,400,302
  302 IF(NSTMT-110) 999,700,303
  303 IF(NSTMT-140) 999,200,304
  304 IF(NSTMT-161) 999,200,305
  305 IF(NSTMT-1142) 999,200,999
  400 CONTINUE
      CALL SECT4
      IF(NSTMT-10) 999,200,401
  401 IF(NSTMT-110) 999,700,402
  402 IF(NSTMT-140) 999,600,403
  403 IF(NSTMT-161) 999,200,999
  500 CONTINUE
      CALL SECT5
      IF(NSTMT-30) 999,200,501
  501 IF(NSTMT-110) 999,700,502
  502 IF(NSTMT-2394) 999,600,999
  600 CONTINUE
      CALL SECT6
      IF(NSTMT-100) 999,500,601
  601 IF(NSTMT-110) 999,700,6020
 6020 IF(NSTMT-520) 999,300,602
  602 IF(NSTMT-1490) 999,500,999
  700 CONTINUE
      CALL THROAT
      IF(NSTMT-497)999,800,999
  800 CONTINUE
```

```
      CALL DIAGNO
      IF(NSTMT-10) 999,100,801
  801 IF(NSTMT-63) 999,400,999
C
C   LAST CASE JUST COMPLETED.   PRINT OUT ALL INPUT TABLES
C     AND TERMINATE PROCESSING.
   99 T=1PGCT
      CALL INTEP(VAR,20,T,P)
      WRITE (6,9001)
      STOP
 9001 FORMAT(1H1 ,14HMAIN STATION 1    )
      END
                     SUBROUTINE SECT1
      COMMON TZZZAY
      DIMENSION TZZZAY(11200)
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
C     IT MUST BE THE FIRST COMMON BLOCK
      COMMON    A        , AJAB     , ALAM     , ALPHAB , ALPHA    , ALPHMB ,
     1          ALPHS    , AM       , AP       , AS     , AT       , BA     ,
     2          BB       , BETAB    , BETAMB   , BETA   , BETAS    , BM     ,
     3          C        , C1       , CAG1     , CAGMB  , CAG      , CALMB  ,
     4 CBG1   , CAL      , CAUS     , CBGMB    , CBG    , CBLMB    , CBL
      COMMON    CDMS     , CDP      , CD       , CFIN   , CFIMS    , CFOM     ,
     6          CFOMS    , CGMB     , CGM      , CGMS   , CLMB     , CLM      ,
     7          CLMS     , CSAVE    , D        , D2     , DA       , DAGE     ,
     8          DD       , DELIM    , DELI     , DELIS  , DELOM    , DELO     ,
     9          DELOS    , DELSI    , DELSO    , DELIM  , DELT     , DELV2
      COMMON    DEMAGB   , DEMAG    , DEMBGB   , DEMBG  , DEMGB    , DINT     ,
     1          DLSIS    , DLSOS    , DO       , DP1    , DP       , DRAY     ,
     2          DPI      , DRO      , DR       , DS1    , DSAVE    , DSLIM    ,
     3          DSMAX    , DSMIN    , DSRAY1   , DSRAY  , DSRPS1   , DSRPS2   ,
     4          DSRES    , DS       , DSA1     , DSX2   , DT11     , DT1B
      COMMON    DTG      , DTHI     , DTHO     , DTL1   , DTLB     , DTL      ,
     6          DT       , DVASQ    , DVBSQ    , DVLSQ  , DX       , DYI      ,
     7          DYO      , EB       , EDS      , EMAGB  , EMAG     , EMBGB    ,
     8          EMBG     , EMGB     , EMG      , EMIS   , EMLD     , EMLM     ,
     9          EML      , EMLS     , EMS      , EMO    , FLECP    , FUR
      COMMON    H        , HJI      , HKAG     , HKGG   , HKGM1    , HKGM2    ,
     1          HKGM     , HKGMS    , HLA1     , HLAM   , HLA      , HLAS     ,
     2          HLB1     , HLEM     , HLD      , HLBS   , HM       , HMS      ,
     3          HOPE     , HT       , IACY     , IDLM   , IDLX     , IGM      ,
     4          IJH      , INT      , ISFT     , ITERO  , K        , K1
      COMMON    K2       , KAP      , KDSCT    , KDS    , KL       , KR1      ,
     6          KR       , KTSCT    , KTJ      , KXP1   , KXP      , L        ,
     7          L1       , L2       , LCT1     , LCT2   , LL       , LPJCT    ,
     8          LSM      , MAG      , MEDO     , MPP    , MSTO     , MM       ,
     9 N      , MOP      , MTHE     , NACV     , N3     , NBLK     , NCTS
      COMMON    NDIAG    , NDS      , NGS      , NTB    , NTS      , NLST     ,
     1          NN       , NNS      , NNOS     , NNN    , NNP      , NS       ,
     2          NNSOO    , NNSO     , NNS      , NP     , NRO      , NS       ,
     3          P        , P10      , P11      , PAS    , PATH     , PA       ,
     4          PAS      , PBS      , PEMB     , PROB   , PRO      , PB
      COMMON    PHS      , PHIAB    , PHIBA    , PHI    , PHIT     , PL       ,
     6          PL1      , PO       , PS       , PT     , Q        , QSD      ,
     7          R1       , RA       , RAS      , RAXO   , RAX      , RB       ,
     8          RC       , RDGLIM   , RDGLOM   , RDIMS  , RDIMS    , RDT      ,
     9          RDM      , RDMS     , RDOLIM   , RDOD   , RHIE     , RHOG3
      COMMON    RHOG     , RHOGS    , RHOLB    , RHOLM  , RHOL     , RHOLS    ,
     1          RIM      , RT       , RM       , ROALB  , ROAL     , ROSLB    ,
     2          ROSL     , ROM      , RO       , R      , RSLIM    , RS       ,
     3          RV3      , RV       , RVG      , S      , S1       , S2       ,
     4          S3       , S4       , SN       , SO     , SGR      , SIG
      COMMON    SIGS     , SMIN     , SMJ1     , SMJ2   , SMLC     , SMLD     ,
     6          SMLE     , SMLF     , SMLG     , SM     , SOJ1     , SOJ2     ,
     7          SOP      , SO       , SOSM     , SS     , STM      , STO      ,
     8          T        , TB       , TDRAY    , TDRAY1 , TEMB     , TEMP     ,
     9          TG       , TGS      , THIN     , THIO   , THIX     , THIS
      COMMON    THOM     , THOO     , THO      , THOS   , TX       , TXT      ,
     1          TLM3     , TLO      , TL       , TLS    , TTT      , TWIM     ,
     2          TWIMS    , TWOM     , TWOMS    , V1     , V2       , VAR      ,
     3          VBD      , VBDS     , VBM      , VBMSQ  , VB       , VBSQ     ,
     4          VDS      , VGO      , VG       , VGSQ   , VGS      , VIAG     ,
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```
      COMMON    VIALB  , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,
     6          VIGMS  , VILB   , VILM   , VILMS  , VLM    , VLO    ,
     7          VL     , VLSQ   , VLS    , VS     , VSS    , WASB   ,
     8          WAG    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,
     9          WBL    , WGB    , WG     , WGS    , WIM    , WIMS   ,
      COMMON    WOM    , WOMS   , X      , X10    , X11    , XCLK   ,
     1          XINT   , XP     , XS     , XX     , XXA    , YI     ,
     2          YIS    , YO     , YOS    , ZZZ    , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1      C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY
     21(100),DRAY(75),HT(18),DIST(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
C     ***********************************************************************
C     **************** STATEMENT NO. 10  ************************************
C     ***********************************************************************
   10 CONTINUE
      NSTMT=9999
C     DO WE HAVE TO WOT  (XX=-1.0 IN MAIN)  SET (POSSIBLY) IN SECT4
      IF(XX+1.0)1,2,1
    1 CONTINUE
      WRITE (6,8077) XX
      XX=-1.0
    2 CONTINUE
C READ INPUTS AND PRINT HEADING FOR THIS CASE
      READ (5,910,END=7777) (DATE(I),I=1,5),(CASE(I),I=1,3),(QID(I),
     1I=1,8),NS,NP
      IF(NS)5,99,11
   99 NSTMT=99
      RETURN
   11 CONTINUE
      READ (5,911) MBU,MOP,MGEO,NDS,NSO,NB,NNS
      READ (5,912) DP,PC,PHI,RAXO,EMT,H,ALAM,DP1,
     1WAL,WBL,SA,SB,DO,PO,TGO,TLO,VGO,VLO,THOO,THIO,EDS,ESO,
     2EB
      WRITE (6,913) DATE,CASE,QID,NS,NP,
     1MBU,MOP,     MGEO,NDS,NSO,NB,     NNS,DP,PC,PHI,RAXO,EMT,
     2H,ALAM,WAL,WBL,SA,SB,DO,PO,TGO,TLO
      WRITE (6,9913) VGO,VLO,THOO,THIO,EDS,ESO,EB,DP1
      NDIAG=0
      NNN=0
      KAT=1
      NACV = 0
      MM=0
      IACV = 0
      KTB = 1
      KDS = 1
       LCT2=0
      K1=1
      K2=1
      KDSCT=0
      KTBCT=0
      NCTS=0
      LCT1=10
      K=1
C
C  GET X(P) TABLE IDENTIFICATION AND X(P) TABLE DATA POINTS.
C
      IF(MOP)1360,14,1360
   14 READ (5,9914) (XXA(I),I=1,8)
      WRITE (6,9915) (XXA(I),I=1,8)
C
C READ IN X(P) TABLE IF MOP=0
      DO 8000 KP=1,75
      DO 8000 JP=1,2
      XP(JP,KP)=-1.0
 8000 CONTINUE
C
    9 READ (5,914) (C(L),L=1,6)
      DO 1320 L=1,5,2
      IF(C(L)-C(L+1))18,15,18
```

```
   15 IF(C(L) - 100000.) 18,9916,18
   18 XP(1,K) =C(L)
      XP(2,K) =C(L+1)
      IF(K-ISET) 19,19,21
   19 K=K+1
 1320 CONTINUE
      GO TO 7
 9916 K = K-1
C        THIS IS A FIX FOR PRESSURE TABLE INTERP AT STEP 51     JHM
      KXP1 = K
C
C PRINTOUT X(P) TABLE JUST READ IN
C
      L1=1
      L2=9
      WRITE (6,915)
   16 WRITE (6,909)  (XP(1,LT),LT=L1,L2)
      WRITE (6,917)  (XP(2,LT),LT=L1,L2)
      LCT1=LCT1+3
      IF(L2-K) 13,22,22
   13 L1=L1+9
      L2=AMIN0(L2+9,K)
      IF(LCT1-54)16,17,17
C
C MAXIMUM LINE COUNT EXCEEDED - START NEW PAGE.
C
   17 WRITE (6,918) LPGCT
      LCT1=4
      LPGCT=LPGCT+1
      GO TO 16
C
C X(P) TABLE LIMITS EXCEEDED - PRINT ERROR MESSAGE AND
C     EXIT TO NEXT CASE.
C
   21 WRITE (6,921)
      GO TO 10
C
   22 CONTINUE
C
C APPROPRIATE TABLES HAVE BEEN READ IN AS REQUIRED
C
 1360 CONTINUE
      WRITE (6,916)
      RETURN
    5 NSTMT=5
      RETURN
 7777 STOP
  909 FORMAT(1H0,3X,5HPRESS,1X,1P9E15.4)
  910 FORMAT(4A4,A2,3A4,7A4,A2,2I6)
  911 FORMAT(11I6)
  912 FORMAT(5E12.6,/,6E12.6,/,6E12.6,/,6E12.6)
  913 FORMAT(1H1 ,  7X, [illegible]
     133HPHASE TWO-COMPONENT NOZZLE FLOW ,/
     2              ,9X,4A4,A2,/,9X,12HCASE NUMBER ,3A4,/,
     39X,7A4,A2,/// ,10X,[illegible],15X,[illegible],9X,3HMBU,9X,3HMOP,
     49X,4HMGZO,9X,3HMMS,9X,[illegible],10X,[illegible],     9X,3HMNS,/,
     5 4(6X,I6),//,20X,2HDT,11X,2HTC,12X,3HPHI,11X,4H[illegible]X),
     612X,[illegible],            14X,1HH,11X,4HALAM,/,11X,7E15.4,
     7//,13X,3HA[illegible]L,12X,3H[illegible]L,13Y,2H[illegible],11X,2HSD,13X,2HDO,13X,
     82H[illegible],12X,3H[illegible]O,12X,3H[illegible]LO,/,11X,1P5E15.4,//,14X,3HVGO,12X,
     93HV[illegible] ,11X,4HT[illegible]CO,11X,4HTHLO,12X,3HDOS,12X,3HESO,13X,2HES)
  914 FORMAT(6E12.6)
  915 FORMAT(1H0,5[illegible]X,16HX(P) TABLE INPUT)
  916 FORMAT(1H0,7X,23HPRINTOUT-STATION OUTPUT  )
  917 FORMAT(1H ,7X,1HX,1X,1P9E15.4)
  918 FORMAT(1H1 ,120X,5HPAGE ,I3,///,55X,18HX(P) TABLE (CONT.))
  921 FORMAT(1H0,29HX(P) TABLE LIMITS EXCEEDED - ,
     118HREAD IN NEXT CASE.)
 9913 FORMAT(1H0,10X,1P7E15.4//19X,3HDP1,
     1/,11X,E15.4)
 9914 FORMAT(7A4,A2)
 9915 FORMAT(1H0,19HX(P) TABLE FOLLOWS ,15X,11HTABLE ID - ,
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     1      7A4,A2)                                                      SEC12120
 8077 FORMAT(1H0,10X,19HISOTHERMAL FLOW TO ,1PE16.4 , 6H PSIA.  )        SEC12130
      END                                                                SEC12140
                    SUBROUTINE SECT2                                     SEC20010
      COMMON TZZZAY                                                      SEC20020
      DIMENSION TZZZAY(11200)                                            SEC20030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP             SEC20050
C     IT MUST BE THE FIRST COMMON BLOCK                                  SEC20060
      COMMON    A      , ABAR   , ALAM   , ALPHAB , ALPHA  , ALPHMB ,    SEC20070
     1          ALPHS  , AM     , AP     , AS     , AT     , BA     ,    SEC20080
     2          BB     , BETAB  , BETAMB , BETA   , BETAS  , BM     ,    SEC20090
     3          C      , C1     , CAG1   , CAGMB  , CAG    , CALMB  ,    SEC20100
     4 CBG1   , CAL    , CASE   , CBGMB  , CHG    , CBLMB  , CBL         SEC20110
      COMMON    CDMS   , CDP    , CD     , CFIM   , CFIMS  , CFOM   ,    SEC20120
     6          CFOMS  , CGMB   , CGM    , CGMS   , CLMB   , CLM    ,    SEC20130
     7          CLMS   , CSAVE  , D      , D2     , DA     , DATP   ,    SEC20140
     8          DD     , DELIM  , DELI   , DELIS  , DELOM  , DELO   ,    SEC20150
     9          DELOS  , DELSI  , DELSO  , DELTM  , DELT   , DELV2       SEC20160
      COMMON    DEMAGB , DEMAG  , DEMBGB , DEMBG  , DEMGB  , DINT   ,    SEC20170
     1          DLSIS  , DLSOS  , DO     , DE1    , DP     , DRAY   ,    SEC20180
     2          DRI    , DRO    , DR     , DS1    , DSAVE  , DSLIM  ,    SEC20190
     3          DSMAX  , DSMIN  , DSRAY1 , DSRAY  , DSRES1 , DSRES2 ,    SEC20200
     4          DSRES  , DS     , DSX1   , DSX2   , DTG1   , DTGB        SEC20210
      COMMON    DTG    , DTHI   , DTHO   , DTL1   , DTLB   , DTL    ,    SEC20220
     6          DT     , DVPSQ  , DVGSQ  , DVLSQ  , DX     , DYI    ,    SEC20230
     7          DYO    , EB     , EDS    , EMAGB  , EMAG   , EMIGB  ,    SEC20240
     8          EMBG   , EMGB   , EMG    , EMGS   , EMLG   , EMLM   ,    SEC20250
     9          EML    , EMLS   , EMT    , ETO    , FLOPP  , FTC         SEC20260
      COMMON    H      , HJI    , HKAG   , HKGG   , HKGM1  , HKGM2  ,    SEC20270
     1          HKGM   , HKGMS  , HLA1   , HLAM   , HLA    , HLAS   ,    SEC20280
     2          HLB1   , HLBM   , HLB    , HLBS   , HM     , HMS    ,    SEC20290
     3          HOPE   , IT     , IACV   , IGLW   , IBLX   , IBW         SEC20300
     4          IJH    , INT    , ISET   , IZERO  , K      , K1          SEC20310
      COMMON    K2     , KAP    , KDICT  , KDS    , KL     , KF1    ,    SEC20320
     6          KR     , KTDCT  , KTB    , KXP1   , KXP    , L      ,    SEC20330
     7          L1     , L2     , LCT1   , LCT2   , LL     , LPGCT  ,    SEC20340
     8          LSW    , MBU    , MFPO   , MFC    , MGMO   , MM     ,    SEC20350
     9 N      , NOP    , NTPT   , NACY   , NB     , NCLK   , NCTS        SEC20360
      COMMON    NDIAG  , NDS    , NGS    , NTB    , NTS    , NLST   ,    SEC20370
     1          NNA    , NN3    , NNOS   , NNN    , NNP    , NN     ,    SEC20380
     2          NNSOO  , NNGO   , NNS    , NP     , NSO    , NS     ,    SEC20390
     3          P      , P10    , P11    , PAB    , PAM3   , PA     ,    SEC20400
     4          PAS    , P33    , PBMB   , PBOG   , PBO    , PB          SEC20410
      COMMON    PBS    , PHTAB  , PHIBA  , PHI    , PINT   , PL     ,    SEC20420
     6          PL1    , PO     , PS     , PT     ,        , PIO    ,    SEC20430
     7          R1     , RA     , RAS    , RAXO   , RAX    , RB     ,    SEC20440
     8          RC     , RDELIM , RDELOM , RDIMS  , RDOMS  , REF    ,    SEC20450
     9          REM    , REMS   , RESLIM , RESO   , RESG   , RHOGB       SEC20460
      COMMON    RHOG   , RHOGS  , RHOLB  , RHOLM  , RHOL   , RHOLS  ,    SEC20470
     1          RIM    , RI     , RM     , ROALB  , ROAL   , ROBLB  ,    SEC20480
     2          ROBL   , ROM    , RO     , R      , RSLIM  , RS     ,    SEC20490
     3          RVB    , RV     , RVS    , S      , S1     , S2     ,    SEC20500
     4          S3     , S4     , SA     , SB     , SGM    , SIG         SEC20510
      COMMON    SIGS   , SMIN   , SMJ1   , SMJ2   , SMLC   , SMLD   ,    SEC20520
     6          SMLB   , SMLF   , SMLG   , SM     , SOJ1   , SOJ2   ,    SEC20530
     7          SOP    , SO     , SOSM   , SS     , SSM    , TBD    ,    SEC20540
     8          T      , TB     , TBRAY  , TBRAY1 , TBMB   , TBO    ,    SEC20550
     9          TG     , TGS    , THIM   , THIO   , THI    , THIS        SEC20560
      COMMON    THOM   , THOO   , THO    , THOS   , TK     , TKI    ,    SEC20570
     1          TLMB   , TLO    , TL     , TLS    , TST    , TWIM   ,    SEC20580
     2          TWIMS  , TWOM   , TWOMS  , V1     , V2     , VAR    ,    SEC20590
     3          VBD    , VBDS   , VBM    , VBMSQ  , V3     , VBGO   ,    SEC20600
     4          VBS    , VGO    , VG     , VGSQ   , VIC    , VIAG        SEC20610
      COMMON    VIALB  , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,    SEC20620
     6          VIGMS  , VILB   , VILM   , VILMS  , VLM    , VLO    ,    SEC20630
     7          VL     , VLSQ   , VLS    , VS     , VSS    , WAGB   ,    SEC20640
     8          WAG    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,    SEC20650
     9          WBL    , WGB    , WG     , WGS    , WIM    , WIMS        SEC20660
      COMMON    WOM    , WOMS   , X      , X10    , X11    , YCLK        SEC20670
     1          XINT   , XP     , XS     , XX     , XXA    , YI     ,    SEC20680
     2          YIS    , YO     , YOS    , ZZZ    , KSTMT                SEC20690
      DIMENSION PL(10)                                                   SEC20700
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      DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),OID(9),XP(2,75),PL1(10),
     1          C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TDRAY(100),TDRAY
     21(100),DRAY(75),HT(10),DINT(9)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-30) 1,30,2
    1 CALL DUMP
    2 IF(NSTMT-145) 1,145,3
    3 IF(NSTMT-161) 1,161,4
    4 IF(NSTMT-1142) 1,1142,5
    5 CONTINUE
C
C  SET ITERATION COUNT ZERO
C
      NNA=0
C
C  SET INITIAL CONDITIONS INDICATION
C
C     *************** STATEMENT NO. 20  ********************************
C     ******************************************************************
   20 MFP=1
      MFPO=1
      IBLK=0
      KAP=1
      NNN=0
      BO=0.0
      PHI=PHI*0.017 5329
      AT=100000.0
C
C INITIALIZE PRINTOUT COUNT
C
      NNP=1
C
C SETUP MIDPOINT AND ENDPOINT INDICATION.
C    INT = 1, NEXT ENTRY TO STATEMENT 32 COMPUTES MIDPOINT
C     QUANTITIES.
C    INT = 0, NEXT ENTRY TO STATEMENT 32 COMPUTES ENDPOINT
C     QUANTITIES.
C
      INT=1
C
C  RESET THROAT INDICATOR
C    MTHT = 0 - THROAT NOT REACHED
C    MTHT = 1 - THROAT REACHED
C
      MTHT=0
C
C  RESET DS ITERATION COUNTER.
C
      NNDS=0
C  RESET OPTIMUM S ITERATION COUNTER.
C
C
      NNSO=0
C
C  BACKSTEP P FOR FIRST ENTRY TO 30
C
      P= PO-DP1/2.0
C
C  SETUP INITIAL CONDITIONS
C
      TG=TGO
      TL=TLO
      VG=VGO
      VL=VLO
      D=DO
   28 X=0.
   27 DTL=0.0
      DS1=0.
      R=0.
      DTG=0.0
      AT=0.
```

```
      VGSQ=VG*VG
      VLSQ=VL*VL
      THO=THOO
      THI=THIO
      DELT=TG-TL
      DELV2=VGSQ-VLSQ
      DS1=0.
      R=0.
      DTHO=0.0
      DTHI=0.0
C
C     **************** STATEMENT NO. 30  **********************************
C     ********************************************************************
   30 NSTMT=9999
      IF(MPP) 631,630,630
C
C  THIS IS FIRST POINT - HALF STEP P BY INITIAL DP STEP-SIZE.
C
  631 P=P+DP1/2.0
      GO TO 632
C
C  THIS IS NOT FIRST POINT - HALF STEP PRESSURE BY STEP
C    SIZE DP.
C
  630 P=P+DP/2.0
  632 IF(P) 1130,1130,131
C
C  STEPPING PRESSURE MADE IT NEGATIVE - PRINT DIAGNOSTIC, AND
C   DATA COMPUTED TO THIS POINT AND GO TO NEXT CASE.
C
 1130 WRITE (6,930)
      LL=1
      GO TO 500
C
C  EXTRAPOLATE TG AND TL, PRINT DIAGNOSTICS IF THEY GO
C    NEGATIVE, AND PRINT DATA COMPUTED TO THIS POINT.
C
  131 CONTINUE
      TG=TG+DTG/2.0
      IF(TG) 132,132,133
  132 WRITE (6,931)
      LL=2
      GO TO 500
  133 TL=TL+DTL/2.0
      IF(TL) 134,134,135
  134 WRITE (6,932)
      LL=3
      GO TO 500
C
C  INTERPOLATE FOR PBO FOR THIS TL
C
  135 N=9
      NN=4
      CALL INTEP(PBO,N,TL,2)
      IF(N) 136,136,137
  136 WRITE (6,9136) HT(NN),TL,P
      LL=3
      GO TO 500
C
C  CHECK DENOMINATOR OF EQUATION FOR PARTIAL PRESSURE
C    OF COMPONENT A, PRINT DIAGNOSTIC IF SUFFICIENTLY
C    CLOSE TO ZERO RENDERING PA INFINITE.
C
  137 IF(ABS(1.0-H*PBO)-.0001) 138,138,139
  138 WRITE (6,938)
      LL=3
      GO TO 500
  139 PA=(P-PBO)/(1.0-H*PBO)
C
C  COMPUTE PA AND PB. IF EITHER IS NEGATIVE, PRINT
C    DIAGNOSTIC AND GO TO NEXT CASE.
C
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      IF(PA) 439,440,440
  439 WRITE (6,9439)
      LL=4
      GO TO 500
  440 PB=P-PA
      IF(PB) 441,442,442
  441 WRITE (6,9440)
      LL=5
      GO TO 500
C
C   INTERPOLATE INTO MOLECULAR WEIGHT OF COMPONENT A
C     GAS TABLE AT TEMPERATURE TG.
C
  442 N=3
      NN=3
      CALL INTEP(WAG,N,TG,PA)
      IF(N) 1141,1141,143
 1141 LL=5
 1142 WRITE (6,9136) HT(NN),TG,PA
      NSTMT=9999
      GO TO 500
C
C   INTERPOLATE INTO MOLECULAR WEIGHT OF COMPONENT B
C     GAS TABLE AT TEMPERATURE TG.
C
  143 N=4
      NN=4
      CALL INTEP(WBG,N,TG,PB)
      IF(N) 144,144,150
  144 LL=6
  145 WRITE (6,9136) HT(NN),TG,PB
      NSTMT=9999
      GO TO 500
C
C   COMPUTE MEAN MOLECULAR WEIGHT OF GAS MIXTURE.
C
  150 WG=(WAG*PA+WBG*PB)/P
C
C   COMPUTE RATIO OF FLOW RATE OF LIQUID A TO FLOW
C     RATE OF LIQUID MIXTURE OF A AND B - ALPHA
C
      ALPHA=((WAL/WBL)*H*PA)/(1.0+((WAL/WBL)-1.0)*H*PA)
C
C   COMPUTE RATIO OF FLOW RATE OF GAS B TO FLOW RATE
C     OF GAS MIXTURE OF A AND B - BETA
C
      BETA=(WBG*PB)/(WG*P)
C
C   COMPUTE RATIO OF FLOW RATE OF LIQUID MIXTURE TO
C     FLOW RATE OF GAS MIXTURE, R. CHECK DENOMINATOR OF
C     EQUATION FOR R AND PRINT DIAGNOSTIC IF SUFFICIENTLY
C     CLOSE TO ZERO.
C
      IF(ABS(1.0-(1.0+RC)*ALPHA)-.0001) 151,152,152
  151 WRITE (6,9151)
      LL=7
      GO TO 500
  152 DR=((RC-(1.+RC)*BETA)/(1.0-(1.0+RC)*ALPHA))-R
      R=R+DR
C
C   COMPUTE GAS DENSITY - RHOG
C
      RHOG=(WG*P)/(TG*10.732)
C
C   INTERPOLATE IN TABLE FOR DENSITY OF LIQUID A AT THIS
C     TEMPERATURE.
C
      N=10
      NN=10
      CALL INTEP(ROAL,N,TL,P)
      IF(N) 160,160,162
C
```

```
C
C  TABLE LIMITS EXCEEDED - WRITE DIAGNOSTIC.
C
  160 LL=8
  161 WRITE (6,9136) HT(NN),TL,P
      NSTMT=1999
      GO TO 500
C
C  INTERPOLATE IN TABLE FOR DENSITY OF LIQUID B AT THIS
C    TEMPERATURE.
  162 N=11
      NN=11
      CALL INTRP(ROBL,N,TL,P)
      IF(N) 161,161,163
C
C  COMPUTE DENSITY OF LIQUID MIXTURE
C
  163 RHOL=1.0/((ALPHA/ROAL)+((1.0-ALPHA)/ROBL))
C
C  COMPUTE FLOW RATES OF LIQUID MIXTURE AND OF GAS MIXTURE.
C
      EMG=EMT/(1.0+R)
      EML=R*EMG
C
C  COMPUTE RATIO OF GAS VOLUME FLOW TO LIQUID VOLUME FLOW.
C
      RV=RHOL/(R*RHOG)
C
C  INTERPOLATE IN SPECIFIC HEAT TABLES FOR A AND B AT
C    THIS TEMPERATURE AND PRESSURE.
C
      N=1
      NN=1
      CALL INTRP(CAG,N,TG,PA)
      IF(N) 165,165,170
  165 LL=9
      GO TO 1142
  170 N=2
      NN=2
      CALL INTRP(CBG,N,TG,PB)
      LL=9
      IF(N) 165,165,171
C  INTERPOLATE INTO LATENT HEAT OF VAPORIZATION TABLES
C    FOR A AND B AT THIS TEMPERATURE.
C
  171 N=7
      NN=7
      CALL INTRP(HLA,N,TL,P)
      LL=9
      IF(N) 161,161,172
  172 N=8
      NN=8
      CALL INTRP(HLB,N,TL,P)
      LL=10
      IF(N) 161,161,31
   31 IF(NFP-1) 32,40,32
   32 IF(IOT-1) 60,50,60
   40 NSTMT=40
      RETURN
   50 NSTMT=50
      RETURN
   60 NSTMT=60
      RETURN
  500 NDIAG=1
      CALL OUTPUT(NNN,LISCT,MG20)
      NSTMT=110
      RETURN
  930 FORMAT(1H0,7X,13HNONPOSITIVE P)
  931 FORMAT(1H0,7X,14HNONPOSITIVE TG)
  932 FORMAT(1H0,7X,14HNONPOSITIVE TL)
  938 FORMAT(1H0,7X,11HINFINITE P1)
 9136 FORMAT(1H0,7X,17HOUTSIDE RANGE OF ,A6,7H TABLE.,5X,
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     14HT = ,1PE12.4,5X,4HP = ,E12.4)                                      SEC21580
9151 FORMAT(1H0,7X,10HINFINITE 9)                                          SEC21590
9439 FORMAT(1H0,7X,11HNEGATIVE PA)                                         SEC21600
9440 FORMAT(1H0,7X,11HNEGATIVE PB)                                         SEC21610
     END                                                                   SEC21620
                 SUBROUTINE SECT3                                          SEC30010
     COMMON TZZZAY                                                         SEC30020
     DIMENSION TZZZAY(11200)                                               SEC30030
C    THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP                SEC30050
C    IT MUST BE THE FIRST COMMON BLOCK                                     SEC30060
     COMMON    A      , A2A3   , ALAM   , ALPHAB , ALPHA  , ALPHMB ,       SEC30070
    1          ALPHS  , AM     , AP     , AS     , AT     , BA     ,       SEC30090
    2          BB     , BETAB  , BETAMB , BETA   , BETAS  , B1     ,       SEC30100
    3          C      , C1     , CAG1   , CAGMB  , CAG    , CALMD  ,       SEC30110
    4 CBG1   , CAL    , CAST   , CBGMB  , CBG    , CBIAB  , CBL    ,       SEC30110
     COMMON    CDMS   , CDP    , CD     , CGIM   , CFIMS  , CGIM   ,       SEC30120
    6          CFOMS  , CGMB   , CGM    , CGMS   , CLMS   , CLM    ,       SEC30130
    7          CLMS   , CSAVE  , D      , D2     , DA     , DATE   ,       SEC30140
    8          DD     , DELIM  , DELT   , DELIS  , DELOM  , DELO   ,       SEC30150
    9          DELOS  , DELSI  , DELGO  , DELTM  , DELT   , DELV2  ,       SEC30160
     COMMON    DEMAGB , DEMAG  , DEMBGB , DEMBG  , DEMG3  , DIFF   ,       SEC30170
    1          DLSIS  , DLMOS  , DO     , DP1    , DP     , DRAY   ,       SEC30180
    2          DPI    , DRC    , DR     , DS1    , DSAVE  , DSLIM  ,       SEC30190
    3          DSMAX  , DSMIN  , DSRAY1 , DSRAY  , DSRES1 , DSRES2 ,       SEC30200
    4          DSRES  , DS     , DSX1   , DSX2   , DTG1   , DTGB   ,       SEC30210
     COMMON    DTG    , DTHI   , DTHO   , DTL1   , DTL3   , DTL    ,       SEC30220
    6          DT     , DVBSQ  , DVGSQ  , DVLSQ  , DX     , DYI    ,       SEC30230
    7          DYO    , EB     , EDS    , EMAGB  , EMAG   , EMBGB  ,       SEC30240
    8          EMBG   , EMGB   , EMG    , EMGS   , EMLD   , EMLM   ,       SEC30250
    9          EML    , EMLS   , EMT    , EPO    , ELSEP  , EOK    ,       SEC30260
     COMMON    H      , HJI    , HKAG   , HKMG   , HKGM1  , HKGM2  ,       SEC30270
    1          HKIM   , HKIMS  , HLA1   , HLAM   , HLA    , HLAS   ,       SEC30280
    2          HLB1   , HLBM   , HLF    , HLGS   , HM     , HMS    ,       SEC30290
    3          HOPE   , HT     , IACV   , IBLM   , IBLX   , IBM    ,       SEC30300
    4          IJJ    , INT    , ISET   , IZERO  , K      , K1     ,       SEC30310
     COMMON    K2     , KAP    , KDJCT  , KDS    , KL     , KR1    ,       SEC30320
    6          KR     , KTBCT  , KTB    , KX01   , KXP    , L      ,       SEC30330
    7          L1     , L2     , LCT1   , LCT2   , LL     , LPTCT  ,       SEC30340
    8          LSM    , MBJ    , MFFO   , MPP    , MSFO   , MM     ,       SEC30350
    9 N      , MOP    , MTHT   , NACV   , NB     , NCLX   , NCSS   ,       SEC30360
     COMMON    NDIAG  , NDS    , NGS    , NIB    , NIS    , NLST   ,       SEC30370
    1          NNA    , NNB    , NNDS   , NNN    , NNP    , NN     ,       SEC30380
    2          NNJOO  , NNSO   , NNX    , NP     , NSO    , NS     ,       SEC30390
    3          P      , P10    , P11    , PAB    , PAMB   , PA     ,       SEC30400
    4          PAS    , PB3    , PBMB   , PBCB   , PBO    , PB     ,       SEC30410
     COMMON    PBS    , PHIAB  , PHIBA  , PHI    , PIHT   , PL     ,       SEC30420
    6          PL1    , PO     , PS     , PT     , Q      , QEO    ,       SEC30430
    7          R1     , RA     , RAS    , RAXO   , RAX    , RB     ,       SEC30440
    8          RC     , RDELIS , RDELOM , RDIMS  , RDOMS  , REF    ,       SEC30450
    9          REM    , REMS   , RESLIM , REGO   , RET6   , RHOGB  ,       SEC30460
     COMMON    RHOG   , RHOGS  , RHOLB  , RHOLM  , RHOL   , RHOLS  ,       SEC30470
    1          RIM    , RI     , RM     , ROALB  , ROAL   , ROBLG  ,       SEC30480
    2          RC3L   , ROM    , RO     , R      , RSLIM  , RS     ,       SEC30490
    3          RV3    , RV     , RVS    , S      , S1     , S2     ,       SEC30500
    4          S3     , S4     , SA     , SB     , SBM    , SET    ,       SEC30510
     COMMON    SIMS   , SMIN   , SMJ1   , SMJ2   , SMLC   , SMLD   ,       SEC30520
    6          SMLE   , SMLP   , SMLG   , SM     , SOJ1   , SOJ2   ,       SEC30530
    7          SOP    , SO     , SOSM   , SS     , SZM    , SZO    ,       SEC30540
    8          T      , TB     , TBRAY  , TBRAY1 , TGMB   , THO    ,       SEC30550
    9          TG     , TGS    , THIM   , THIO   , THI    , THIS   ,       SEC30560
     COMMON    THOM   , THOO   , THO    , THOS   , TK     , TMP    ,       SEC30570
    1          TLMB   , TLO    , TL     , TLS    , TOT    , TWLX   ,       SEC30580
    2          TWIMS  , TWOM   , TWOMS  , V1     , V2     , VAL    ,       SEC30590
    3          VBO    , VBOS   , VBS    , VBMSQ  , V3     , VBSG   ,       SEC30600
    4          VBS    , VGO    , VG     , VGSQ   , VGS    , VIAG   ,       SEC30610
     COMMON    VIALB  , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,       SEC30620
    6          VIGMS  , VILB   , VILM   , VILMS  , VLM    , VLO    ,       SEC30630
    7          VL     , VLSQ   , VIS    , VS     , VSM    , WAGB   ,       SEC30640
    8          WAG    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,       SEC30650
    9          WBL    , WGB    , WG     , WGS    , WIM    , WIMS   ,       SEC30660
     COMMON    WOM    , WOMS   , X      , X10    , X11    , XCLK   ,       SEC30670
    1          XINT   , XP     , XS     , XX     , XXA    , YI     ,       SEC30680
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     2        YIS      , YO       , YOS      , ZZZ      , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1     C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY
     21(100),DRAY(75),HT(18),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-40) 1,40,2
    1 CALL DUMP
    2 IF(NSTMT-50) 1,50,1
C
C  THIS IS FIRST POINT - STORE INITIAL PROPERTIES FOR USE
C    AT END OF FIRST INTERVAL.
C
C     **************** STATEMENT NO. 40  ********************************
C     *******************************************************************
   40 NPP=0
      NSTMT=9999
      HLA1=HLA
      HLB1=HLB
      CAG1=CAG
      CBG1=CBG
C
C  COMPUTE INITIAL FLOW RATES OF COMPONENTS A AND B.
C
      EMAG=(EMG*WAG*PA)/(WG*P)
      EMBG=(EMG*WBG*PB)/(WG*P)
      OR=0.0
      IF(VG) 175,175,174
  174 IF(VL) 175,175,176
  175 A=1000000.
      RA=A
      GO TO 41
C
C  COMPUTE INITIAL AREA OF NOZZLE.
C
  176 A=144.*EMG*((1.0/(RHOG*VG))+(R/(RHOL*VL)))
      RA=RV*VL/VG
   41 AT=A
      PT=P
      AP(1,1)=P
      AP(2,1)=A
      KAP=2
C
C  COMPUTE SLIP VELOCITY, VS, MEAN FREE STREAM VELOCITY, VB, AND
C    SLIP FRACTION, S.
C
   42 VS=VG-VL
      VB=(VG+R*VL)/(1.0+R)
      VBSQ= VB*VB
      S=VS/VB
      IF(TGZ0) 180,179,180
C
C  NOZZLE IS CIRCULAR - COMPUTE DISTANCE FROM NOZZLE AXIS TO
C    WALL OF NOZZLE, YI.
C
  179 YO=SQRT(A/3.1416)
      YI=0.0
      RI=0.0
      GO TO 43
C
C  NOZZLE IS ANNULAR - COMPUTE RADII AND DISTANCES TO WALL
C    OF ANNULAR NOZZLE, RI,RO,YI,YO.
C
  180 TST=(RAXC**2)-((A*COS(PHI))/(2.0*3.1416))
      IF(TST) 181,182,182
  181 WRITE (6,9181)
      LL=11
      GO TO 500
  182 RI=SQRT(TST)
      RO=(RAXO**2)+((A*COS(PHI))/(2.0*3.1416))
      RO=SQRT(RO)
```

```
      YI=(RAXO-RI)/COS(PHI)
      YO=(RO-RAXO)/COS(PHI)
C
C WRITE LINES 1,2,3 OF OUTPUT AND GO TO 30.
C
   43 IF(LCT1-42)644,643,643
  643 LCT1=0
      WRITE (6,9643) LPGCT
      LPGCT=LPGCT+1
  644 WRITE (6,1001) X,P,R,V3,A,TG,TL,VG,VL
      WRITE (6,1002) VS,S,D,WV,RA,ALPHA,BETA,EMG,EML
      WRITE (6,1003) RHOG,RHOL,WAG,WBG,WG,PA,PB,HLA,HLB
      LCT1=LCT1+9
      GO TO 30
C
C  MIDPOINT OF INTERVAL - COMPUTE MID-POINT PARAMETERS.
C    RESET MIDPOINT/ENDPOINT INDICATOR SO NEXT ENTRY TO 32
C    WILL BE AN ENDPOINT.
C
C     **************** STATEMENT NO. 50 ***********************************
C     *********************************************************************
   50 INT=0
      NSTRT=9999
C
C  INTERPOLATE IN VISCOSITY (GAS) TABLES FOR A AND B AT
C    THIS GAS TEMPERATURE.
C
      N=16
      NN=16
      CALL INTRP(VIAG,N,TG,PA)
      IF(N)205,205,206
  205 LL=12
      GO TO 1142
  206 N=17
      NN=17
      CALL INTRP(VIBG,N,TG,PB)
      IF(N)207,207,208
  207 LL=12
      GO TO 145
C
C  INTERPOLATE IN SPECIFIC HEAT TABLES FOR A AND B AT
C    THIS LIQUIDS TEMPERATURE.
C
  208 N=5
      NN=5
      CALL INTRP(CAL,N,TL,P)
      LL=12
      IF(N)161,161,209
  209 NN=6
      N=6
      CALL INTRP(CBL,N,TL,P)
      LL=12
      IF(N)161,161,210
C
C  COMPUTE MEAN SPECIFIC HEATS OF LIQUID, CLM, AND OF
C    GAS, CGM.
C
  210 CLM=ALPHA*CAL+(1.0-ALPHA)*CBL
      CGM=(1.0-BETA)*CAG+BETA*CBG
      PHIAB=((1.0+((VIAG/VIBG)**.5)*((WBG/WAG)**.25))**2)/
     1      (2.824*((1.0+WAG/WBG)**.5))
      PHIBA=((1.0+((VIBG/VIAG)**.5)*((WAG/WBG)**.25))**2)/
     1      (2.824*((1.0+WBG/WAG)**.5))
C
C  COMPUTE MEAN VISCOSITY OF A AND B GAS.
C
      VIGM=(VIAG/(1.0+(BETA/(1.0-BETA))*(WAG/WBG)*PHIAB))+
     1     (VIBG/(1.0+(((1.0-BETA)/BETA)*(WBG/WAG)*PHIBA)))
C
C  INTERPOLATE IN VISCOSITY (LIQUID) TABLES FOR A AND B AT
C    THIS TEMPERATURE.
C
```

```
      N=14
      NN=14
      CALL INTRP(VIAL,N,TL,P)
      LL=13
      IF(N) 161,161,215
  215 N=15
      NN=15
      CALL INTRP(VIBL,N,TL,P)
      LL=13
      IF(N) 161,161,216
C
C   COMPUTE MEAN THERMAL CONDUCTIVITY OF GAS MIXTURE, HKGM.
C      BA AND BB ARE USE SUBSEQUENTLY IN DETERMINING HKGM.
C
  216 VILM=ALPHA*VIAL+(1.0-ALPHA)*VIBL
      T1=(SQRT(SA*SB)/TG+1.0)*0.25
      T2=1.0+SA/TG
      T3=1.0+SB/TG
      T4=T2/T3
      T5=(WAG/WBG)**0.75
      T6=VIAG/VIBG
      T7=SQRT(T6*T4*T5)
      BA=T1/T2*(1.0+T7)**2
      BB=T1/T3*(1.0+1.0/T7)**2
C
C     INTERPOLATE IN THERMAL CONDUCTIVITY TABLES FOR COMPONENTS
C      A AND B IN GASEOUS STATE.
C
      N=12
      NN=12
      CALL INTRP(HKAG,N,TG,P)
      LL=13
      IF(N) 145,145,220
  220 N=13
      NN=13
      CALL INTRP(HKBG,N,TG,P)
      LL=13
      IF(N) 145,145,221
C
C     IF BETA=1, FIRST TERM OF HKGM IS SET=0
C     IF BETA=0, SECOND TERM OF HKGM IS SET=0
C
  221 IF(BETA-1.0) 223,222,223
  222 HKGM1=0.0
      GO TO 224
  223 HKGM1=HKAG/(1.0+(BETA/(1.0-BETA))*(WAG/WBG)*BA)
  224 IF(BETA) 225,225,226
  225 HKGM2=0.0
      GO TO 227
  226 HKGM2=HKBG/(1.0+((1.0+BETA)/BETA)*(WBG/WAG)*BB)
  227 HKGM=HKGM1+HKGM2
C
C     COMPUTE V1,V2,R1, TERMS FOR USE IN ITERATIVE LOOP AT
C     STATEMENT NO. 70.
C
      V1=((99403.6*TG)/((1.0+R)*WG))*ALOG
     1      ((P+DP/2.0)/(P-DP/2.0))
      V2=(9206.38*D*DF)/((1.0+R)*RHOL)
      R1=(300.5*RHOG*D)/VIGM
      IF(MOP) 51,52,51
C
C    OPTIMUM X(F) IS TO BE USED.
C
C     ***************** STATEMENT NO. 51  ***************************************
C     ******************************************************************************
   51 C1=(D*ALAM*RHOL)/(9.0*RHOG)
      SMLG=R/((1.0+R)**2)
16070 KDS = 1
      KDSCT = 0
      NNSO = 0
      NNSOO = 0
      DSBIN = -2.*(S+(1.+R)/R)+1.0E-06
```

```
      DSMAX = 1.0 + R - 1.0E-06
      GO TO 70
C
C   SPECIFIED X(P) IS TO BE USED.
C
   52 P10=P+DP/2.0
      P11=P-DP/2.0
      PINT=P10
      KL=1
      GO TO 1100
 1152 X10=XINT
      PINT=P11
      KL=2
      GO TO 1100
 1153 X11=XINT
C
C   GET DIFFERENCE OF INTERPOLATED X VALUES FROM
C    X(P) TABLE
C
      DX=X10-X11
      S1=(0.75*RHOG*(1.0+R)*DX)/(D*RHOL)
      S2=(4633.04*(1.0+R)*DP)/RHOL
      S3=(1.0+R)/2.0
      S4=2.0*DS/(1.0+R)
      GO TO 16070
C
C   INTERPOLATE INTO X(P) TABLE FOR TWO PRESSURE VALUES
C    AT EITHER SIDE OF CURRENT INTERVAL.
C
 1100 CONTINUE
C     THIS CHANGE TO ALLOW FOR MONOTONIC INCREASING OR DECREASING TABLES
      TERZ=PINT-XP(1,1) +1.0E-6
      IF(TERZ*(XP(1,1)-XP(1,2))) 1106,1102,1105
 1106 CONTINUE
      DO 1103 KR=2,KXP1
      TERY=XP(1,KR)-PINT
      IF(TERY*TERZ) 1101,1104,1104
 1101 TERZ=-TERY
 1103 CONTINUE
      GO TO 1120
 1102 CONTINUE
      KR=2
 1104 KR1=KR-1
      XINT=XP(2,KR1)+TERZ/(XP(1,KR)-XP(1,KR1))*(XP(2,KR)-XP(2,KR1))
      GO TO (1152,1153),KL
 1105 CONTINUE
      IF (TERZ-0.001) 1108,1120,1120
 1108 IF (TERZ+0.001) 1120,1120,1110
 1110 TERZ=-1.00*TERZ
      GO TO 1106
 1120 WRITE (6,9105) P10,P11,KL,TERZ,TERY,PINT
      LL=14
      GO TO 500
   30 NSTMT=30
      RETURN
 1142 NSTMT=1142
      RETURN
  145 NSTMT=145
      RETURN
  161 NSTMT=161
      RETURN
   70 NSTMT=70
      RETURN
  500 NDIAG=1
      CALL OUTPUT(NNN,LPGCT,NGEO)
      NSTMT=110
      RETURN
C
C   FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.
C
 1001 FORMAT(1H0,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,
     12HTL,12X,2HVG,12X,2HVL,/,6X,1P9E14.4)
```

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1002 FORMAT(1H0,12X,2HVG,13X,1HS,13X,1HP,12X,2HRV,12X,2HRA,9X,      SEC31530
    15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,1P9E14.4)           SEC31540
1003 FORMAT(1H0,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,    SEC31550
    112X,2HPA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,1P9E14.4)            SEC31560
9105 FORMAT(1H0,18HSTEP 52 - PRESSURE OUT OF RANGE OF XP           SEC31570
    1       16HTABLE.    P1 = ,1PE14.4,3X,5HP2 = ,E14.4,/,7X,7HPROCESS,  SEC31580
    2       29H CONTINUED TO NEXT CASE.,27H  OUTPUT OF LAST ITERATION , SEC31590
    3       4HFCLL)=3./T20,3L20.7)                                 SEC31600
9181 FORMAT(1H0,7X,11HNEGATIVE RT)                                  SEC31610
9643 FORMAT(1H1,120X,5HPAGE ,I3,/,1H0,28HREAL TWO-PHASE TWO-COMPONENT SEC31620
    1,12H NOZZLE FLOW// )                                          SEC31630
     END                                                           SEC31640
                    SUBROUTINE SECT4                               SEC40010
     COMMON TZZZAY                                                 SEC40020
     DIMENSION TZZZAY(11200)                                       SEC40030
C    THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP        SEC40050
C    IT MUST BE THE FIRST COMMON BLOCK                             SEC40060
     COMMON      A      , ABAR   , ALAM   , ALPHAB , ALPHA  , ALPHMB , SEC40070
    1            ALPHS  , AM     , AP     , AS     , AT     , BA     , SEC40080
    2            BB     , BETAB  , BETAMB , BETA   , BETAS  , BM     , SEC40090
    3            C      , C1     , CAG1   , CAGMB  , CAG    , CALMB  , SEC40100
    4  CBG1   ,  CAL    , CAGS   , CBGMB  , CDG    , CDLMB  , CAL    , SEC40110
     COMMON      CDMS   , CDP    , CD     , CFIM   , CFIMS  , CFOM   , SEC40120
    6            CFOMS  , CFOM   , CGP    , CIMS   , CLMB   , CLM    , SEC40130
    7            CLMS   , CSAVE  , D      , D2     , DA     , DATE   , SEC40140
    8            DD     , DELIM  , DELI   , DELIS  , DELOM  , DELO   , SEC40150
    9            DFLOS  , DELSI  , DFLSO  , DELIM  , DELT   , DELV2  , SEC40160
     COMMON      DEMAGB , DEMAG  , DEMBGB , DEMBG  , DEMGB  , DINT   , SEC40170
    1            DLSIS  , DLSOS  , DO     , DP1    , DP     , DRAY   , SEC40180
    2            DRI    , DRO    , DR     , DS1    , DSAVE  , DSLIM  , SEC40190
    3            DSMAX  , DSMIN  , DSPAY1 , DSRAY  , DSRES1 , DSRES2 , SEC40200
    4            DSRES  , DS     , DSA1   , DSX2   , DT21   , DT1B   , SEC40210
     COMMON      DT3    , DTHI   , DTHO   , DTL1   , DTLB   , DTL    , SEC40220
    6            DT     , DVBSQ  , DVGSQ  , DVLSQ  , DX     , DY1    , SEC40230
    7            DY0    , EB     , EDG    , EMAGB  , EMAG   , EMBGB  , SEC40240
    8            EMBG   , EMGB   , EMG    , EMGS   , EMLB   , EMLM   , SEC40250
    9            EML    , EMLS   , EMT    , ESO    , FLSEP  , FUX    , SEC40260
     COMMON      H      , HJI    , HKAG   , HKEG   , HKEM1  , HKEM2  , SEC40270
    1            HKGM   , HKGMS  , HLA1   , HLAM   , HLA    , HLAS   , SEC40280
    2            HLB1   , HLBM   , HLP    , HLBS   , HM     , HMS    , SEC40290
    3            HOPE   , HT     , IACV   , IBLA   , IBLX   , IJH    , SEC40300
    4            IJH    , INT    , ISET   , IZERO  , K      , K1     , SEC40310
     COMMON      K2     , KAP    , KDSCT  , KDS    , KL     , KR1    , SEC40320
    6            KP     , KTPCT  , KTS    , KXP1   , KXP    , L      , SEC40330
    7            L1     , L2     , LCT1   , LCT2   , LL     , LPNCT  , SEC40340
    8            LSW    , MBH    , MPPO   , MSP    , MGEO   , MM     , SEC40350
    9  N      ,  MOP    , MTHT   , NACV   , NB     , NCLK   , NCTS   , SEC40360
     COMMON      NDIAG  , NDS    , NGG    , NTB    , NIS    , NLS1   , SEC40370
    1            NNA    , NNB    , NNDS   , NNN    , NNP    , NN     , SEC40380
    2            NNSOO  , NNSO   , NNS    , NP     , NSC    , NS     , SEC40390
    3            P      , P10    , P11    , PAB    , PAMB   , PA     , SEC40400
    4            PAS    , PBJ    , PBMB   , PROB   , PJO    , PB     , SEC40410
     COMMON      PBS    , PHIAB  , PHIBA  , PHI    , PINT   , PL     , SEC40420
    6            PLI    , PO     , PS     , PT     , Q      , QID    , SEC40430
    7            R1     , RA     , RAS    , RAYO   , RAY    , RB     , SEC40440
    8            RC     , RDELIM , RDELOM , RDIMS  , RDOMS  , REF    , SEC40450
    9            REM    , RESS   , RESLIM , RESO   , RESZ   , RHOGB  , SEC40460
     COMMON      RHOG   , RHOGS  , RHOLB  , RHOLM  , RHOL   , RHOLS  , SEC40470
    1            RIM    , RI     , RM     , ROALB  , ROAL   , ROBLB  , SEC40480
    2            ROBL   , ROM    , RO     , R      , RSLIM  , RS     , SEC40490
    3            RVB    , RV     , RVS    , S      , S1     , S2     , SEC40500
    4            S3     , S4     , SA     , SB     , SGN    , SIG    , SEC40510
     COMMON      SIGS   , SMIN   , SMJ1   , SMJ2   , SMLC   , SMLD   , SEC40520
    6            SMLE   , SMLP   , SMLG   , SM     , SOJ1   , SOJ2   , SEC40530
    7            SOP    , SO     , SOSM   , SS     , SZM    , SZO    , SEC40540
    8            T      , TB     , TBRAY  , TBRAY1 , TBRB   , TBO    , SEC40550
    9            TG     , TGS    , THIM   , THIO   , THI    , THIS   , SEC40560
     COMMON      THOM   , THOO   , THO    , THOS   , TK     , TKT    , SEC40570
    1            TLMB   , TLO    , TL     , TLS    , TST    , TWIM   , SEC40580
    2            TWIMS  , TWOM   , TWOMS  , V1     , V2     , VAR    , SEC40590
    3            VBD    , VBDS   , VBM    , VBMSQ  , V3     , VBSQ   , SEC40600
    4            VBS    , VGO    , VG     , VGSQ   , VGS    , VIAG     SEC40610
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      COMMON    VIALD  , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,
     6          VIGMS  , VILM   , VILM   , VILMS  , VLM    , VLO    ,
     7          VL     , VLSQ   , VLS    , VS     , VSS    , WATB   ,
     8          WAS    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,
     9          WEL    , WGB    , WG     , WGS    , WIM    , WIMS   ,
      COMMON    WOM    , WOMS   , X      , X10    , X11    , XCLK   ,
     1          XINF   , XP     , XS     , XX     , XXA    , YI     ,
     2          YIS    , YO     , YOS    , ZZZ    , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(4),XP(2,75),PL1(10),
     1          C(5),X2(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY
     21(100),DRAY(75),HT(10),DINT(9)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-60) 1,60,2
    1 CALL DUMP
    2 IF(NSTMT-63) 1,63,1
C
C     END POINT OF THIS INTERVAL OF PRESSURE.
C       COMPUTE CHANGES IN FLOW PARAMETERS THIS INTERVAL.
C
C       **************** STATEMENT NO. 60  ************************************
C       ***********************************************************************
   60 INT=1
      NSTMT=9999
      VB=ABS(SQRT(VBSQ))
C
C     COMPUTE NEW SLIP FRACTION, S, AND NEW DISTANCE, X.
C
      IF(MFPO-1) 4001,4000,4001
 4000 S=S1
      GO TO 4002
 4001 S=S+DS
 4002 X=X+DX
C
C     COMPUTE CHANGES IN SQUARE OF GAS AND LIQUID VELOCITIES.
C
      DVGSQ=((1.0+(R*S)/(1.0+R))**2)*VBSQ-VGSQ
      DVLSQ=((1.0-S/(1.0+R))**2)*VBSQ-VLSQ
C
C     COMPUTE CHANGES IN GAS AND LIQUID FLOW RATES.
C
      DEMAG=(EMG*WAG*PA)/(WG*P)-EMAG
      DEMBG=(EMG*WBG*PB)/(WG*P)-EMBG
C
C     COMPUTE CHANGES IN GAS AND LIQUID TEMPERATURES.
C
      DTL=(1.0/CLM)*((((HM*DELTM*DX)/(600.*D*RHOLM*VLM))
     1        -(HLAM*DEMAG/EMLM)-(HLBM*DEMBG/EMLM))
      DELT=TG-TL
      DTG=(-1.0/CGM)*((DVGSQ/50072.9)+R*
     1        (CLM*DTL+DP/(5.4037*RHOLM)+DVLSQ/50072.9)+
     2        ((DEMAG+DEMBG)*DELV2)/(50072.9*EMG)+
     3        ((HLA1+CAG1*DELT)*DEMAG+(HLB1+CBG1*DELT)*
     4DEMBG)/EMG)
      IF((1.0 + (R * CLM / CGM)) * ((HM * DX) / (600.0 * D * CLM * RHOL
     1M * VLM)) - 1.) 8075,8076,8076
 8076 DTL = 0.
      DTG = 0.0
      IF(P-0.5*PO) 8075,8074,8074
 8074 CONTINUE
C     THIS LAST TEST ADDED TO DELETE NEXT TEST AT END OF NOZZLE
      AX=P
C     CHANGE TO SAVE THE LAST P FOR PRINTOUT IN SECT1.
 8075 CONTINUE
C   COMPUTE NEW TEMPERATURES FOR LIQUID AND GAS.
C     IF EITHER IS NEGATIVE PRINT DIAGNOSTIC AND EXIT
C     TO NEXT CASE.
      VGSQ=VGSQ+DVGSQ
      IF(VGSQ) 230,230,231
  230 WRITE (6,9230)
      LL=15
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```
      GO TO 500
  231 VLSQ=VLSQ+DVLSQ
      IF(VLSQ) 232,232,233
  232 WRITE (6,9212)
      LL=15
      GO TO 500
C
C     COMPUTE NEW VELOCITIES FOR LIQUID AND GAS.
C
C
  233 VG=ABS(SQRT(VGSQ))
      VL=ABS(SQRT(VLSQ))
C
C     COMPUTE RATIO OF GAS FLOW AREA TO LIQUID FLOW AREA.
C
      RA=RV*(VL/VG)
C
C     COMPUTE NEW LIQUID AND GAS FLOW RATES.
C
      EMAG=EMAG+DEMAG
      EMBG=EMBG+DEMBG
      DELV2=VGSQ-VLSQ
C
C     SET UP INITIAL QUANTITIES FOR NEXT END-POINT.
C
      DTL1=DTL
      DTG1=DTG
      HLA1=HLA
      HLB1=HLB
      DELT=TG-TL
      CAG1=CAG
      CBG1=CBG
      VS=S*VR
C
C     INTERPOLATE INTO SURFACE TENSION TABLE AT THIS LIQUID
C      TEMPERATURE.
C
      N=18
      NN=14
      CALL INTRP(SIG,N,TL,R)
      LL=16
      IF(R) 161,161,240
C     IF DROPLET BREAKUP OPTION SPECIFIED, COMPUTE DROPLET
C      DIAMETER.
  240 IF(MPU-1) 243,238,243
  238 D2=(.3174*SIG)/(RHOG*VS**2)
      IF(D-D2) 243,243,239
  239 D=D2
C
C     COMPUTE CHANGE IN NOZZLE CROSS-SECTIONAL AREA SINCE
C      LAST END-POINT.
C
  243 DA=144.0*EMG*(1.0/(RHOG*VG)+R/(RHOL*VL))-A
C
C     COMPUTE MEAN AREA BETWEEN THIS AND PREVIOUS ENDPOINT.
C
      AM=A+DA/2.0
C
C     COMPUTE PRESENT AREA
C
      A=A+DA
      IF(MGEO-1)67,68,67
C
C     COMPUTE RADII AND DISTANCE FROM AXIS TO WALL OF
C      CIRCULAR NOZZLE.
C     *************** STATEMENT NO. 67 ********************************
C     *****************************************************************
   67 DYO=SQRT(A/3.1416)-YO
      RCM=YO+DYO/2.0
      DRO=DYO
      YO=YO+DYO
      RO=YO
```

```
      WIM=0.0
      DELI =0.0
      DELSI=0.0
      RDELIM=0.0
      CFIM=0.0
      TWIM =0.0
      GO TO 69
C
C     COMPUTE GEOMETRY OF ANNULAR NOZZLE AND BOUNDARY-LAYER
C      GROWTH AND SHEAR FOR INNER WALL.
C
   68 RAX=RAXO-X*SIN(PHI)
      IF(RAX**2-(A*COS(PHI))/(2.0*3.1416)) 241,242,242
  241 WRITE (6,9241)
      LL=17
      GO TO 500
  242 DRI=SQRT(RAX**2-(A*COS(PHI))/(2.0*3.1416))-RI
      DRO=SQRT(RAX**2+(A*COS(PHI))/(2.0*3.1416))-RO
      RIM=RI+DRI/2.0
      RI=RI+DRI
      ROM=RO+DRO/2.0
      RO=RO+DRO
      DYI=(RAX-RI)/(COS(PHI))-YI
      DYO=(RO-RAX)/(COS(PHI))-YO
      YI=YI+DYI
      YO=YO+DYO
C
C     COMPUTE ANGLE OF NOZZLE INNER WALL RELATIVE TO AXIS.
C
      WIM=(ATAN(DYI/DX))
      WIM=WIM*57.29578
  246 DTHI=0.5*CFIM*((AM*BM)/(1.0+RM))*DX- THIM*
     1      ((1.141*DVRSQ)/VBMSQ-DA/AM+DRI/RIM)
      TWIM=(CFIM*RHOL*VLSQ)/(6559.6*(1.0+RA))
      THI=THI+DTHI
      DELI=10.286*THI
      DELSI=1.2857*THI
   69 DTHO=0.5*CFOM*((AM*BM)/(1.0+RM))*DX-THOM*
     1      ((1.141*DVRSQ)/VBMSQ-DA/AM+DRO/ROM)
      TWOM=(CFOM*RHOL*VLSQ)/(6559.6*(1.0+RA))
      THO=THO+DTHO
      DELO=10.286*THO
      DELSO=1.2857*THO
C
C     COMPUTE ANGLE OF NOZZLE OUTER WALL RELATIVE TO AXIS.
C
      WOM=ATAN(DYO/DX)
      WOM=57.29578*WOM
C
C     COMPUTE MEAN VELOCITY (INCLUDING BOUNDARY LAYER).
C
  251 VBO=VB*(1.0-((2.0*3.1416)/A)*
     1      (RO*THO+RI*THI))
      GO TO 61
C
C     IF AREA LESS ZERO, NOZZLE IS CONVERGING AND THROAT HAS
C      NOT JUST BEEN PASSED. IF NOT, NOZZLE THROAT MAY
C      HAVE JUST BEEN PASSED.
C
   61 IF(A-AT) 66,62,62
C
C     ADVANCE STEP COUNT AND RETURN TO STEP 30 IF MAXIMUM
C       STEP COUNT NOT REACHED.
C
   62 NNS=NNS+1
      IF(NNS-NS) 30,260,260
C
C     INITIALIZE TB AND COUNTERS AND GO TO STEP 140 TO
C       COMPUTE BARRED QUANTITIES.
C
  260 TB=TL
      NNS=0
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```
      NNB=1
      GO TO 140
C
C    OUTPUT HAS JUST BEEN PRINTED.  RETURN TO STEP 30
C      IF ITERATION IS NOT COMPLETED.
C
   63 NNP=NNP+1
      NSTRT=9999
      IF(NNP-NP)30,64,64
C
C
   64 PL1(1)=XS
      PL1(2)=PS
      PL1(3)=RS
      PL1(4)=VBS
      PL1(5)=AS
      PL1(6)=TGS
      PL1(7)=TLS
      PL1(8)=VGS
      PL1(9)=VLS
      PL1(10)=1.0
C     WRITE (18) PL1
      MM=MM+1
  264 CALL OUTPUT (NNN,LPGCT,NGEO)
      GO TO 110
   66 AT=A
      PT=P
      XS=X
      PS=P
      TLS=TL
      VGS=VG
      RS=R
      VBS=VB
      AS=A
      TGS=TG
      VLS=VL
      VSS=VS
      SS=S
      DD=D
      PVS=PV
      PAS=PA
      ALPHS=ALPHA
      BETAS=BETA
      EMGS=EMG
      EMLS=EML
      RHOGS=RHOG
      RHOLS=RHOL
      WAGS=WAG
      WBGS=WBG
      WGS=WG
      TAS=TA
      PBS=PB
      HLAS=HLA
      HLBS=HLB
      SIGS=SIG
      CGMS=CGM
      CLMS=CLM
      VIGMS=VIGM
      VILMS=VILM
      HKGMS=HKGM
      REMS=REM
      CDMS=CD
      HMS=HM
      YOS=YO
      WOMS=WOM
      THOS=THO
      DELOS=DELO
      DLSOS=DLSO
      RDOMS=RDELOM
      CPOMS=CPCM
      TWOMS=TWCM
      VBDS=VBD
```

```
      YIS=YI                                                            SEC4 1440
      WIMS=WIM                                                          SEC4 1450
      THIS=THI                                                          SEC4 1460
      DELIS=DELI                                                        SEC4 1470
      DLSIS=DELSI                                                       SEC4 1480
      RDIMS=RDELIM                                                      SEC4 1490
      CFIMS=CFIM                                                        SEC4 1500
      TWIMS=TWIM                                                        SEC4 1510
      GO TO 62                                                          SEC4 1520
   30 NSTMT=30                                                          SEC4 1530
      RETURN                                                            SEC4 1540
  140 NSTMT=140                                                         SEC4 1550
      RETURN                                                            SEC4 1560
  161 NSTMT=161                                                         SEC4 1570
      RETURN                                                            SEC4 1580
  500 NDIAG=1                                                           SEC4 1590
      CALL OUTPUT(NNN,LPGCT,NGEO)                                       SEC4 1600
  110 NSTMT=110                                                         SEC4 1610
      RETURN                                                            SEC4 1620
 9230 FORMAT(1H0,7X,14HNONPOSITIVE VG)                                  SEC4 1630
 9232 FORMAT(1H0,7X,14HNONPOSITIVE VL)                                  SEC4 1640
 9241 FORMAT(1H0,7X,11HNEGATIVE RI)                                     SEC4 1650
      END                                                               SEC4 1660
                      SUBROUTINE SECT5                                  SEC5 0010
      COMMON TZZZAY                                                     SEC5 0020
      DIMENSION TZZZAY(11200)                                           SEC5 0030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP            SEC5 0050
C     IT MUST BE THE FIRST COMMON BLOCK                                 SEC5 0060
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  , SEC5 0070
     1          ALPHS   , AM      , AP      , AS      , AT      , BA      , SEC5 0080
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      , SEC5 0090
     3          C       , C1      , CAG1    , CAGMB   , [illegible] , CALMB , SEC5 0100
     4 CBG1   , CAL     , CAME    , CBGMB   , CDG     , [illegible] , CDL , SEC5 0110
      COMMON    CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFOM    , SEC5 0120
     6          CFOMS   , CGMJ    , CGM     , CGMS    , [illegible] , CLM , SEC5 0130
     7          CLMS    , CSAVE   , D       , D2      , DA      , DATE    , SEC5 0140
     8          DD      , DELIM   , DELI    , DELIS   , DELOM   , DELO    , SEC5 0150
     9          DELOS   , DELSI   , DELSO   , DELTM   , DELT    , DELV2   , SEC5 0160
      COMMON    DEMAGB  , DEMAG   , DENBGB  , DENUG   , DENGB   , DIST    , SEC5 0170
     1          DLSIS   , DLSOS   , DO      , DP1     , DP      , DRAY    , SEC5 0180
     2          DRI     , DRO     , DR      , DS1     , DSAVE   , DSLIM   , SEC5 0190
     3          DSMAX   , DSMIN   , DSRAY1  , DSRAY   , DSRES1  , DSRES2  , SEC5 0200
     4          DSRES   , DS      , DSX1    , DSX2    , DT1     , DT3     , SEC5 0210
      COMMON    DTG     , DTHI    , DTHO    , DTL1    , DTLB    , DTL     , SEC5 0220
     6          DT      , DVBSQ   , DVGSQ   , DVLSQ   , DX      , DY1     , SEC5 0230
     7          DYD     , EB      , EDS     , EMAGB   , EMAG    , EMAGB   , SEC5 0240
     8          EMRG    , EMRB    , EMS     , EMSS    , EMLB    , EMLM    , SEC5 0250
     9          EML     , EMLS    , EML     , ESO     , ELESP   , EUK     , SEC5 0260
      COMMON    H       , HJI     , HKAG    , HKOG    , HKGM1   , HKGM2   , SEC5 0270
     1          HKGM    , HKGMS   , HLA1    , HLAM    , HLA     , HLAS    , SEC5 0280
     2          HLB1    , HLBM    , HLB     , HLBS    , HM      , HMS     , SEC5 0290
     3          HOPE    , HT      , IACV    , ITLW    , TOLX    , IBW     , SEC5 0300
     4          IJH     , INT     , ISFT    , IZERO   , K       , K1      , SEC5 0310
      COMMON    K2      , KAP     , KOSCT   , KDS     , KL      , KR1     , SEC5 0320
     6          KR      , KTPCT   , KT3     , KXP1    , KXP     , L       , SEC5 0330
     7          L1      , L2      , LCT1    , LCT2    , LL      , LPGCT   , SEC5 0340
     8          LSW     , MDT     , MFEO    , MFP     , MGEO    , MM      , SEC5 0350
     9 N      , MOP     , MTHT    , NACV    , NB      , NCLK    , NCPS    , SEC5 0360
      COMMON    NDIAG   , NDS     , NGS     , NIJ     , NIS     , NLST    , SEC5 0370
     1          NNA     , NNB     , NNPS    , NNN     , NNP     , NN      , SEC5 0380
     2          NNSOO   , NNSO    , NNS     , NP      , NSO     , NS      , SEC5 0390
     3          P       , P10     , P11     , PAB     , PAMB    , PA      , SEC5 0400
     4          PAJ     , PBJ     , PBMB    , PROB    , PBO     , P3      , SEC5 0410
      COMMON    PBS     , PHIAB   , PHIBA   , PHI     , PINT    , PL      , SEC5 0420
     6          PL1     , PO      , PS      , PT      , Q       , QID     , SEC5 0430
     7          R1      , RA      , RAS     , RAXO    , RAX     , RB      , SEC5 0440
     8          RC      , RDELIM  , RDELOM  , RDIMS   , RDOMS   , REF     , SEC5 0450
     9          REM     , REMS    , RESLIM  , RESO    , RESZ    , RHOGB   , SEC5 0460
      COMMON    RHOG    , RHOGS   , RHOLB   , RHOLM   , RHOL    , RHOLS   , SEC5 0470
     1          RIM     , RI      , RM      , ROALB   , ROAL    , ROBLB   , SEC5 0480
     2          ROBL    , ROM     , RO      , R       , RSLIM   , RS      , SEC5 0490
     3          RVB     , RV      , RVS     , S       , S1      , S2      , SEC5 0500
```

```
     4                                                                                
      COMMON    S3      , S4      , SA      , SB      , SGN     , SIG     ,
     5          SIGS    , SMIN    , SMJ1    , SMJ2    , SMLC    , SMLD    ,
     6          SMLE    , SMLP    , SMLG    , SM      , SOJ1    , SOJ2    ,
     7          SOP     , SO      , SOSM    , SS      , SOM     , SZO     ,
     8          T       , TB      , TBRAY   , TBRAY1  , TGHB    , TGI     ,
     9          TG      , TGS     , THIM    , THIO    , THI     , THIS    ,
      COMMON    THOM    , THOO    , THO     , THOS    , TK      , TKT     ,
     1          TLMB    , TLO     , TL      , TLS     , TST     , TWIM    ,
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAR     ,
     3          VBD     , VBDS    , VBM     , VBMSO   , VB      , VBSO    ,
     4          VBS     , VBO     , VG      , VGSO    , VGS     , VIAG    ,
      COMMON    VIALB   , VIAL    , VIRG    , VIBLB   , VIBL    , VIGM    ,
     6          VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,
     7          VL      , VLSO    , VLS     , VS      , VSS     , WAGB    ,
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,
     9          WBL     , WGB     , WG      , WGS     , WIM     , WIMS    ,
      COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLK    ,
     1          XINT    , XP      , XS      , XX      , XXA     , YI      ,
     2          YIS     , YO      , YOS     , ZZZ     , NSTMT
      DIMENSION PL(10)
        DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),QID(8),XP(2,75),PL1(10),
     1          C(6),AP(2,75),XXA(9),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAY
     21(100),DRAY(75),HT(14),DINT(9)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-70) 1,70,2
    1 CALL DUMP
    2 IF(NSTMT-100)1,100,3
    3 IF(NSTMT-1400) 1,1400,1
C     ***************** STATEMENT NO. 70  ********************************
C     *******************************************************************
C
C     DELTA S ITERATION ROUTINE.
C
   70 CONTINUE
      NSTMT=9999
16004 CONTINUE
      IF(S+DS1)25070,25060,25070
25060 CONTINUE
      S=1.0E-5
C     FOLLOWING STATEMENT SIMPLIFIED BY UNIVAC.
C     SO=-SIGN(1.0,DP*ZZZ) ... ETC.
25070 CONTINUE
      IF(MOD) 2470,2399,2470
 2470 CONTINUE
      DSMIN=1.0E-6-2.0*(S+(1.0+B)/B)
      DSMAX=1.0+H-1.0E-6
      DSLIM=DSMIN
      IF(DS) 3000,3010,3010
 3000 CONTINUE
      DSLIM=DSMAX
 3010 CONTINUE
      IJH=1
      SM=0.0
      GO TO 16000
 3030 CONTINUE
      IJH=2
      RESO=SOSM
      SMJ1=SM
      SOJ1=SO
      SM=DSLIM
      GO TO 16000
 3031 CONTINUE
      PSLIM=SOSM
      SMJ2=SM
      SOJ2=SO
      IF(RESO*PSLIM) 3090,3060,3060
 3060 CONTINUE
      WRITE (6,3061) DSLIM,DP
      GO TO 3090
 3071 CONTINUE
      RESZ=SOSM
```

```
      SZO=SO
      SZM=SM
      HOPE=RESC*RESZ
      IF(HOPE) 3080,3085,3085
 3080 CONTINUE
      RSLIM=RESZ
      DSLIM=SZM
      SOJ2=SZO
      GO TO 3090
 3085 CONTINUE
      RZSO=RESZ
      SMJ1=SZM
      SOJ1=SZO
 3090 CONTINUE
      SM=(SMJ1+DSLIM)/2.0
      IJH=0
16000 CONTINUE
      IF(ABS(SM)-SMIN) 1390,1390,1391
 1390 CONTINUE
      SM=-SIGN(SMIN,DP)
 1391 AM=1.0+(R*SM)/(1.0+R)
      BM=1.0-SM/(1.0+R)
      DVBSQ=(-V1/AM)-(V2/BM)
      VBMSQ=VBSQ+DVBSQ/2.0
C
C    WRITE DIAGNOSTIC IF VBM NON-POSITIVE.
C
      IF(VBMSQ) 1250,1250,1251
 1250 CONTINUE
      WRITE (6,9250) SM,AM,BM,V1,V2,VBSQ,DVBSQ,R,VBMSQ
      LL=1H
      GO TO 1492
C
C    COMPUTE VBM
C
 1251 VBM=SQRT(VBMSQ)
      REM=R1*VBM*ABS(SM)
      IF(REM-.000001) 1258,1258,1259
 1258 CD=2.4E07
      GO TO 71
 1259 IF(REM-0.1) 1260,1260,1263
 1263 IF(REM-20000.) 1261,1264,1264
 1264 CD=0.4569
      GO TO 71
 1260 CD=24.0/REM
      GO TO 71
 1261 CD=EXP(3.271-0.8893*(ALOG(REM))+0.03417*
     1((ALOG(REM))**2)+.001441*((ALOG(REM))**3))
   71 CONTINUE
C     **************** STATEMENT NO. 80  ************************************
C     ***********************************************************************
C
C    OPTIMUM SM IS TO BE USED.
C
   80 IF(REM-.1611) 1380,1380,1381
 1380 CDP=1.0
      GO TO 1384
 1381 IF(REM-4700.) 1382,1382,1383
 1382 CDP=1.1137+.068834*(ALOG(REM))+.004129*((ALOG(REM))**2)
      GO TO 1384
 1383 CDP=2.0
 1384 SMLC=(C1*(BM**2))/(VBMSQ*CD )
      SMLD=(RHOL*(BM**2))/(RHOG*(AM**2))
      SMLE=((RHOL*(BM**2))/(RHOG*AM*(1.0+R)))+
     1((R*SM)/(1.0+R))-1.0
      SMLF=SMLE*(((2.0*AM)/(R*BM))+1.0)+1.0
C     D=1 TO 0                                  JHH 8/19/66
      ZZZ=SMLF*SMLG*SM+SMLE*CDP
      SO = -SIGN(1.0,DP*ZZZ)
      C2 = 2.0*SMLG*SMLD
      C2 = SMLC*ZZZ/C2
      IF(C2.LT.0.0) C2=ABS(C2)
```

```
      C2 = C2**0.33333
      SO = SO*C2
      SOSM = SO-SM
   81 IF(ABS(SO-SM)-ESO)1481,1481,1482
 1481 NIS=NNSO
      NNSO=0
      REWIND 16
      GO TO 42
C**********THIS IS TO BYPASS ITERATION COUNTER DURING PLOTTING IJH = 4
 1482 CONTINUE
11482 NNSO = NNSO + 1
16060 IF (NNSO-NSO)  1483,1483,1490
C
C  STORE THIS VALUE OF DS1 AND WRITE DS1 ARRAY IF FULL.
C
 1483 CONTINUE
C*********DEBUGGING AID FOR BINARY CUT CONVERGENCE
      DSRAY(KDS)=22222222.
      DSRAY(KDS+1)  =  SOJ1
      DSRAY(KDS+2)  =  SCJ1
      DSRAY(KDS+3)  =  RCSO
      DSRAY(KDS+4)  =  SM
      DSRAY(KDS+5)  =  SO
      DSRAY(KDS+6)  =  SOSM
      DSRAY(KDS+7)  =  DSLIM
      DSRAY(KDS+8)  =  SOJ2
      DSRAY(KDS+9)  =  RSLIM
      KDS = KDS + 10
      IF(KDS - 100) 16003,16003,1484
 1484 WRITE (16) DSRAY
      KDSCT=KDSCT+1
      DO 1486  I=1,100
      DSRAY(I) =0.0
 1486 CONTINUE
      KDS=1
16003 CONTINUE
      GO TO (3030,3031,3071),IJH
C******END OF BINARY CUT CONVERGENCE ROUTINE
C
C   NO CONVERGENCE ON DS  -  PRINT DIAGNOSTIC AND GET ALL
C       PREVIOUS VALUES OF DS FROM TAPE 16 AND TEMPORARY STORAGE IN
C       DSRAY.   PRINT THEM ANDEXIT TO DIAGNOSTIC ROUTINE.
C
 1490 REWIND 16
      NSTOT=9999
      WRITE (6,9490)
 1491 IF(KDSCT)1493,1493,1492
 1492 READ (16) DSRAY1
      WRITE (6,9491)  (DSRAY1(I),I=1, 100)
      KDSCT=KDSCT-1
      GO TO 1491
 1493 WRITE (6,9491)  (DSRAY(I),I=1,KDS)
      KDS=1
      KDSCT=0
      DO 1495  I=1,100
      DSRAY(I) =0.0
 1495 CONTINUE
      LL=IR
      REWIND 16
      GO TO 500
C
C   OPTIMIZE DS AND DX.
C
   82 IF(MFPO-1)2382,2381,2382
 2381 DS=0.0
      S=SO
       MFPO=0
      GO TO 93
 2382 DS=SO-SOF
   83 SOF=SO
      DX=(D/(0.75*RHOG*ABS(SM)*SM*CD*VRMSQ))
     1        *(4633.04*DP+(((BM**2)*RHOL*DVBSQ)/2.0))
```

```
     2      +((RM*RHOL*VBMSQ)/(1.0+R))*(((2.0*SM*DT)/(1.0+R))-DS))
 100  DS1=DS
      NSTMT=9999
      VBSQ=VBSQ+DVBSQ
      IF(VBSQ) 300,300,301
 300  WRITE (6,9300)
      LL=19
      GO TO 500
C
C     STORE MIDPOINT QUANTITIES FOR NEXT END-POINT.
C
 301  EMLM=EML
      RHCLM=RHCL
      DELTM=TG-TL
      VLM=SM*VBS
      HLAM=HLA
      HLBM=HLB
      RM=R
C
C     DETERMINE HEAT TRANSFER COEFFICIENT.   SEGMENTS ARE NOT
C        CONTINUOUS AT JUNCTIONS.
C
      IF(REN-1.0) 304,304,305
 304  HN=(24.0*HKGM)/D
      GO TO 308
 305  IF(REN-25.0) 306,306,307
 306  HN=3600.*CGM*RHOL*(ABS(SM))*VBM*
     1      ((2.2/REN)+(.48/(SQRT(REN))))
      GO TO 308
 307  HN=(4.44*HKGM*(REN**.6))/D
C
C     COMPUTE MEAN BOUNDARY-LAYER PARAMETERS FOR CIRCULAR NOZZLE
C        OR OUTER WALL OF ANNULAR NOZZLE.
C
 308  THOM=THO+DTHO/2.0
      DELOM=10.285*THOM
      RDELOM=(300.*RHOL*VL*DELOM)/VILM
      IF(RDELOM.LT.0.0) RDELOM=ABS(RDELOM)
      CFOM=.208/((ALOG10(RDELOM)+.425)**2.584)
      IF(NGEO) 309,30,309
 309  THIM=THI+DTHI/2.0
      DELIM=10.285*THIM
      RDELIM=(300.*RHOL*VL*DELIM)/VILM
      CFIM=.208/((ALOG10(RDELIM)+.425)**2.584)
  30  NSTMT=30
      RETURN
2399  NSTMT=2399
      RETURN
 500  NDIAG=1
      CALL OUTPUT(NNN,LPRCT,NGEO)
      NSTMT=110
      RETURN
9250  FORMAT(1H0,7X,15HNONPOSITIVE VBM/(1H ,9X,1P6E15.6))
9300  FORMAT(1H0,7X,14HNONPOSITIVE VB)
9490  FORMAT(1H0,7X,24HCOULD NOT CONVERGE ON DS,//)
9491  FORMAT(1H ,1P10E13.4)
3061  FORMAT(1H0,35HLIKE SIGN RESIDUES IN INTERVAL 0 TO    ,1PE12.4,
     119HFOR DP = ,E15.4)
      END
                    SUBROUTINE SECT6
      COMMON TZZZAY
      DIMENSION TZZZAY(11200)
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
C     IT MUST BE THE FIRST COMMON BLOCK
      COMMON     A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMB  ,
     1           ALPHS   , AM      , AP      , AS      , AT      , BA      ,
     2           BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,
     3           C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,
     4 CBG1    , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL
      COMMON     CDMS    , CDP     , CD      , CFIM    , CFIMS   , CFOM    ,
     6           CFOMS   , CGMB    , CGM     , CGMS    , CLMB    , CLM     ,
     7           CLMS    , CSAVE   , D       , D2      , DA      , DATE    ,
```

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9          DD      , DELIM  , DELI   , DELIS  , DELOM  , DELO   ,         SEC60150
9          DELOS   , DELSI  , DELSO  , DELSM  , DELT   , DELV2  ,         SEC60160
 COMMON    DEMAGB  , DEMAG  , DEMDGB , DEMDG  , DEMGB  , DINT   ,         SEC60170
1          DLSIS   , DLSOS  , DO     , DP1    , DP     , DRAY   ,         SEC60180
2          DPI     , D20    , DR     , DS1    , DSAVE  , DSLIM  ,         SEC60190
3          DSMAX   , DSMIN  , DSRAY1 , DSRAY  , DSRES1 , DSRES2 ,         SEC60200
4          DSRES   , DS     , DSX1   , DSX2   , DT1    , DTAB             SEC60210
 COMMON    DT3     , DTHI   , DTHO   , DTL1   , DTL3   , DTL    ,         SEC60220
6          DT      , DVBSQ  , DVGSQ  , DVLSO  , DX     , DYI    ,         SEC60230
7          DYD     , EB     , EDS    , EMAGB  , EMAG   , EMBGB  ,         SEC60240
8          EMBG    , EMGB   , EMI    , EMIS   , EMLB   , EMLM   ,         SEC60250
9          EKL     , FMLS   , EMT    , EOD    , FLZEP  , PUX    ,         SEC60260
 COMMON    H       , HJI    , HKAG   , HKUG   , HKGM1  , HKGM2  ,         SEC60270
1          HKGM    , HKGMS  , HLA1   , HLAM   , HLA    , HLAS   ,         SEC60280
2          HLB1    , HL3M   , HLB    , HLBS   , HM     , HMS    ,         SEC60290
3          HOPE    , HT     , IACV   , IDLW   , IDLX   , IGW    ,         SEC60300
4          IJH     , INT    , ISET   , IZERO  , K      , K1     ,         SEC60310
 COMMON    K2      , KAP    , KDSCT  , KDS    , KL     , KR1    ,         SEC60320
6          KR      , KTDCT  , KTB    , KXP1   , KXP    , L      ,         SEC60330
7          L1      , L2     , LCT1   , LCT2   , LL     , LPTCT  ,         SEC60340
8          LSW     , MBU    , MFDO   , MPP    , NGEO   , MM     ,         SEC60350
9 N      , MOP     , MTMT   , NACV   , NB     , NCLK   , NCTS   ,         SEC60360
 COMMON    NDIAG   , NDS    , NGG    , NIB    , NIS    , NLST   ,         SEC60370
1          NNA     , NNB    , NNOS   , NNA    , NNP    , NN     ,         SEC60380
2          NNSOO   , NNSO   , NNS    , NP     , NSC    , NS     ,         SEC60390
3          P       , P10    , P11    , PAB    , PAMB   , PA     ,         SEC60400
4          PAS     , PBB    , PBMB   , PBOB   , PBO    , PB               SEC60410
 COMMON    PBS     , PHIAB  , PHIBA  , PHI    , PINT   , PL     ,         SEC60420
6          PL1     , PO     , PS     , PT     , Q      , QID    ,         SEC60430
7          R1      , PA     , RAS    , RAXO   , RAX    , RB     ,         SEC60440
8          RC      , RDELIM , RDELOM , RDLMS  , RDOMS  , REF    ,         SEC60450
9          RPM     , REMS   , RESLIM , RESO   , RETA   , RHOGB            SEC60460
 COMMON    RHOG    , RHOGS  , RHOLB  , RHOLM  , RHOL   , RHOLS  ,         SEC60470
1          RIM     , RI     , RM     , ROALB  , ROAL   , ROBLB  ,         SEC60480
2          ROBL    , ROM    , RO     , R      , RSLIM  , RS     ,         SEC60490
3          RVR     , RV     , RVS    , S      , S1     , S2     ,         SEC60500
4          SJ      , SW     , SA     , SB     , SIN    , SIG    ,         SEC60510
 COMMON    SIGS    , SMIN   , SMJ1   , SMJ2   , SMLC   , SMLD   ,         SEC60520
6          SMLE    , SMLF   , SMLG   , SM     , SOJ1   , SOJ2   ,         SEC60530
7          SOP     , SO     , SORM   , SS     , SZM    , SZO    ,         SEC60540
8          T       , TB     , TBRAY  , TBRAY1 , TCMB   , TGG    ,         SEC60550
9          TG      , TGS    , THIN   , THIO   , THI    , THIS             SEC60560
 COMMON    THOM    , THOO   , THO    , THOS   , TK     , TKI    ,         SEC60570
1          TLMB    , TLO    , TL     , TLS    , TST    , TWIM   ,         SEC60580
2          TWIMS   , TWOM   , TWOMS  , V1     , V2     , VAC    ,         SEC60590
3          VBD     , VBDS   , VBM    , VBMSQ  , VB     , VBSQ   ,         SEC60600
4          VCG     , VGO    , VG     , VGSQ   , VGS    , VIAL   ,         SEC60610
 COMMON    VIALB   , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,         SEC60620
6          VIMOG   , VILB   , VILM   , VILMS  , VLM    , VLO    ,         SEC60630
7          VL      , VLSQ   , VLS    , VS     , VSS    , WAGB   ,         SEC60640
8          WAG     , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,         SEC60650
9          WBL     , WGP    , WG     , WGS    , WIM    , WIMS   ,         SEC60660
 COMMON    WOM     , WOMS   , X      , X10    , X11    , XCLK   ,         SEC60670
1          XINT    , XP     , XS     , XX     , XXA    , YI     ,         SEC60680
2          YIS     , YO     , YOS    , ZZZ    , NSTMT                     SEC60690
 DIMENSION PL(10)                                                          SEC60700
  DIMENSION NDRAY(75)                                                      SEC60710
 DIMENSION DATE(5),CASE(3),QTD(9),XP(2,75),PL1(10),                        SEC60720
1          C(6),AP(2,75),XXA(3),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAYSEC60730
21(100),DRAY(75),HT(18),DIST(8)                                            SEC60740
 EQUIVALENCE (NDRAY(1),DRAY(1))                                            SEC60750
 IF(NSTMT-140) 1,140,2                                                     SEC60760
1 CALL DUMP                                                                SEC60770
2 IF(NSTMT-2399) 1,2399,1                                                  SEC60780
C                                                                          SEC60790
C  COMPUTE BARRED QUANTITIES AND ITERATE FOR CONVERGENCE ON TB.            SEC60900
C  GET INTERPOLATED PBO FROM TABLE FOR THIS TB.                            SEC60910
C                                                                          SEC60920
140 N=9                                                                    SEC60930
    NSTMT=9999                                                             SEC60940
339 NN=9                                                                   SEC60950
    CALL INTEP(PBOB,N,TB,2)                                                SEC60960
```

```
      IF(N) 318,318,320
  318 LL=20
  319 WRITE (6,9318) HT(NN),TB,P
      GO TO 500
C
C        COMPONENT A.    PRINT DIAGNOSTIC IF SUFFICIENTLY CLOSE TO ZERO.
C
  320 IF(ABS(1.0-H*PBOD)-.0001) 321,321,323
  321 WRITE (6,9320)
      LL=20
      GO TO 500
C
C   COMPUTE PARTIAL PRESSURE OF COMPONENT A AND B AND
C      PRINT DIAGNOSTIC IF EITHER NONPOSITIVE.
C
  323 PAB=(P-PEOB)/(1.-(H*PBOD))
      IF (PAB) 310,322,322
  322 PBB = P-PAB
      IF(PBB) 312,9323,9323
C
C   INTERPOLATE INTO MOLECULAR WEIGHT TABLES FOR A AND B
C      AT THIS TEMPERATURE AND PRESSURE.
C
 9323 N=3
      NN=3
      CALL INTEP(WAGB,N,TB,PAB)
      IF(N) 325,325,327
  325 LL=22
      WRITE (6,9318) HT(NN),TB,PAB
      GO TO 500
  327 N=4
      NN=4
      CALL INTEP(WBGB,N,TB,PBB)
      IF(N) 329,329,330
  329 LL=23
      WRITE (6,9318) HT(NN),TB,PBB
      GO TO 500
  310 WRITE (6,9310)
      LL=20
      GO TO 500
  312 WRITE (6,9312)
      LL=21
      GO TO 500
C
C   COMPUTE MEAN MOLECULAR WEIGHT.
C
  330 WGB=((WAGB*PAB)+(WBGB*PBB))/P
C
C   COMPUTE ALPHA AND BETA.
C
      ALPHAB=((WAL/WBL)*H*PAB)/
     1       (1.0+((WAL/WBL)-1.0)*H*PAB)
      BETAB=(WBGB*PBB)/(WGB*P)
C
C   CHECK DENOMINATOR OF EQUATION FOR R AND PRINT
C      DIAGNOSTIC IF SUFFICIENTLY CLOSE TO ZERO.
C
      TK=(1.0-(1.0+RC)*ALPHAB)
      TKT=ABS(TK)
      IF(TKT-.0001) 333,335,335
  333 WRITE (6,9333)
      LL=24
      GO TO 500
C
C   COMPUTE BARRED FLOW PARAMETERS.
C
  335 RB=(RC-(1.0+RC)*BETAB)/TK
      DEMGB=(EBT/(1.0+RB))-EMG
      EMGB=EMG+DEMGB
      EMLB=RB*EMGB
      DEMAGB=((EMGB*WAGB*PAB)/(WGB*P))-EMAG
      DEMBGB=((EMGB*WBGB*PBB)/(WGB*P))-EMBG
```

```
      EMAGB=EMAG+DEMAGB
      EMBGB=EMBG+DEMBGB
      DTGB=TB-TG
      TLMB=(TL+TB)/2.0
      TGMB=(TG+TB)/2.0
      PAMB=(PA+PAB)/2.0
      PBMB=(PB+PBB)/2.0
C
C     INTERPOLATE INTO SPECIFIC HEAT TABLES FOR
C          CALMB  -  SPECIFIC HEAT - LIQUID A
C          CBLMB  -  SPECIFIC HEAT - LIQUID B
C          CAGMB  -  SPECIFIC HEAT - GAS A
C          CBGMB  -  SPECIFIC HEAT - GAS B
C
      N=5
      NN=5
      CALL INTEP(CALMB,N,TLMB,P )
      IF(N) 340,340,341
  340 WRITE (6,9136) HT(NN),TLMB,P
      LL=25
      GO TO 500
  341 N=6
      NN=6
      CALL INTEP(CBLMB,N,TLMB,P)
      IF(N) 340,340,343
  343 N=1
      NN=1
      CALL INTEP(CAGMB,N,TGMB,PAB)
      IF(N) 344,344,345
  344 LL=25
      WRITE (6,9136) HT(NN),TGMB,PAB
      GO TO 500
  345 N=2
      NN=2
      CALL INTEP(CBGMB,N,TGMB,PBB)
      IF(N) 346,346,347
  346 LL=25
      WRITE (6,9136) HT(NN),TGMB,PBB
      GO TO 500
  347 ALPHMB=(ALPHA+ALPHAB)/2.0
      BETAMB=(BETA+BETAB)/2.0
      CLMB=(ALPHMB*CALMB)+(1.0-ALPHMB)*CBLMB
      CGMB=(1.0-BETAMB)*CAGMB+BETAMB*CBGMB
      DTLB=(-1.0/(EB*CLMB))*((CGMB*DTGB)+
     1     ((VBSQ-VG**2+EB*(VBSQ-VL**2))/50072.9)+
     2     ((DEMAGB/EMGB)*(HLA+CAG*(TG-TL)))+
     3     ((DEMBGB/EMGB)*(HLB+CBG*(TG-TL)))+
     4     ((DEMGB/EMGB)*(((VG**2)-(VL**2))/50072.9)))
C
C     TEST FOR CONVERGENCE ON TB.
C
      IF((ABS((TB-TL)-DTLB))-EB) 141,141,350
  350 NNB=NNB+1
      IF(NNB-NB) 351,351,354
C
C     SAVE THIS VALUE OF TB FOR POSSIBLE NON-CONVERGENCE.
C
  351 TB=TL+DTLB
      TBRAY(KTB)=TB
      KTB=KTB+1
      IF(KTB-100) 140,140,352
  352 WRITE (14) TBRAY
      DO 353 I=1,100
      TBRAY(I)=0.0
  353 CONTINUE
      KTB=1
      KTBCT=KTBCT+1
       GO TO 140
C
C     NO CONVERGENCE ON TB AND ITERATION MAXIMUM REACHED.
C        PRINT DIAGNOSTIC AND ALL VALUES OF TB FOUND.
C
```

```
  354 WRITE (6,9352)
  399 IF(KTBCT)403,403,400
  400 READ (14) TBRAY1
      WRITE (6,9491) (TBRAY1(I),I=1,100)
      KTBCT=KTBCT-1
      GO TO 399
  403 WRITE (6,9491) (TBRAY(I),I=1,KTB)
C
C   CLEAR TB SAVE ARRAY.
C
      KTB=1
      KTBCT=0
      DO 405 I=1,100
      TBRAY(I) = 0.0
  405 CONTINUE
      LL=26
      GO TO 500
C   STORE NUMBER OF ITERATIONS REQUIRED TO CONVERGE ON TB.
C
C
C     **************** STATEMENT NO. 140 *********************************
C     ********************************************************************
  141 NIR=NND
      NND=1
C
C   COMPUTE DENSITY OF GAS MIXTURE.
C
      RHOGB=(WGB*P)/(10.732*TB)
C
C   INTERPOLATE FOR DENSITIES OF LIQUIDS A AND B.
C
      N=10
      NN=10
      CALL INTRP(ROALB,N,TB,P)
      LL=27
      IF(N) 319,319,360
  360 N=11
      NN=11
      CALL INTRP(ROBLB,N,TB,P)
      LL=27
      IF(N) 319,319,363
C
C   COMPUTE DENSITY OF LIQUID MIXTURE.
C
  363 RHOLB=1.0/((ALPHAB/ROALB)+((1.0-ALPHAB)/(ROBLB)))
      ABAR=((144.0*EMGP)*(1.0/RHOGB+RB/RHOLB))/VB
      RVB=RHOLB/(RB*RHOGB)
      Q=(RHOLB*ABAR*VB)/(144.0*EMLB)
C
CC   INTERPOLATE INTO VISCOSITY TABLES FOR LIQUID A AND B.
C
      N=14
      NN=14
      CALL INTRP(VIALB,N,TB,P)
      LL=28
      IF(N) 319,319,366
  366 N=15
      NN=15
      CALL INTRP(VIBLB,N,TB,P)
      IF(N) 369,369,370
  369 LL=29
      GO TO 319
  370 VILB=ALPHAB*VIALB+(1.0-ALPHAB)*VIBLB
      REF=(8617.2*EMLB)/(VILB*(SQRT(ABAR)))
C  ENTER CURRENT VALUES OF A AND R INTO A VS R TABLE
C
  529 ISTMT=529
       RETURN
C
C     ********************************************************************
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C   FIND GOOD APPROXIMATION FOR DS1 TO USE IN SUCCESSIVE
```

```
C       SUBSTITUTION ROUTINE AT STEP 90.
C
  2399 KDSCT=0
       NSIMT=9999
       IBLW=0
       KDS=1
       NNCS=0
       SGN=0.5
       DSMIN=1.0E-6-2.0*(S+(1.0+R)/R)
       DSMAX=1.0+R-1.0E-6
 12399 CONTINUE
       DS1=DSMIN
       IBW=1
       GO TO 5000
  2401 CONTINUE
       DSX1=DS1
       DSRES1=DSRES
       DS1=DSMAX
       IBW=2
       GO TO 5000
  2402 CONTINUE
       DSX2=DS1
       DSRES2=DSRES
       IF(IBLX) 12402,2403,12402
 12402 CONTINUE
       DS1=DSAVE
       GO TO 12403
  2403 CONTINUE
       DS1=DSX1-DSRES1*(DSX2-DSX1)/(DSRES2-DSRES1)
       IBLX=1
 12403 CONTINUE
       IBW=3
       GO TO 5000
  2404 CONTINUE
       IF(DSRES*DSRES1) 2405,2406,2406
  2405 CONTINUE
       DSRES2=DSRES
       DSX2=DS1
       SGN=-1.0*SGN
       GO TO 2407
  2406 CONTINUE
       DSRES1=DSRES
       DSX1=DS1
  2407 CONTINUE
       IF(SGN) 12407,2408,2408
 12407 CONTINUE
       DS1=DSX2
       GO TO 2409
  2408 CONTINUE
       DS1=DSX1
  2409 CONTINUE
       DS1=DS1+SGN
       IF(DS1-DSMAX) 2410,2410,5060
  2410 CONTINUE
       IF(DS1-DSMIN) 5060,12410,12410
 12410 CONTINUE
       IBW=4
       GO TO 5000
 12411 CONTINUE
       IF(SGN) 12414,12412,12412
 12412 CONTINUE
       IF(DSRES*DSRES2) 2406,12413,12413
 12413 CONTINUE
       DSRES2=DSRES
       DSX2=DS1
       GO TO 12416
 12414 CONTINUE
       IF(DSRES*DSRES1) 12417,12415,12415
 12415 CONTINUE
       DSRES1=DSRES
       DSX1=DS1
 12416 CONTINUE
```

```
      SGN=SGN/10.0
      IBLW=IBLW+1
      IF(IBLW-5) 2403,2403,5060
12417 CONTINUE
      DSRES2=DSRES
      DSX2=DS1
      GO TO 2409
C
C      EVALUATE DS FOR GIVEN DS1.    TEST FOR CONVERGENCE
C
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
 5000 CONTINUE
      SM=S+DS1/2.0
      AM=1.0+(R*SM)/(1.0+R)
      BM=1.0-SM/(1.0+R)
      DVBSQ=(-V1/AM)-(V2/BM)
      VBMSQ=VBSQ+DVBSQ/2.0
      IF(VBMSQ)6000,5001,5001
 6000 CONTINUE
      WRITE (6,7021) SM,S,DS1,AM,B,BM,DVBSQ,V1,V2,VBMSQ,VBM
 5001 CONTINUE
      VBM=SQRT(VBMSQ)
      REM=R1*VBM*ABS(SM)
      IF(REM-.000001)5015,5015,5005
 5005 IF(REM-0.1)5020,5020,5010
 5010 IF(REM-20000.)5030,5025,5025
 5015 CD=2.4E07
      GO TO 5035
 5020 CD=24.0/REM
      GO TO 5035
 5025 CD=0.4553
      GO TO 5035
 5030 CD=EXP(3.271-0.8893*(ALOG(REM))+0.03417*
     1((ALOG(REM))**2)+.001443*((ALOG(REM))**3))
 5035 CONTINUE
      DSMP=-((S1*ABS(SM)*SM*CD)/BM)+(S2/(BM*VBMSQ))
     1+((S3*A1*DVBSQ)/VBMSQ)+S4*SM
      DSRES=SMP-DS1
      IF(ABS(DSRES)-EDS)91,91,5040
 5040 DSRAY(KDS)=DS1
      DSRAY(KDS+1)=DSRES
      KDS=KDS+2
      IF(KDS-100)5055,5055,5045
 5045 WRITE (16) DSRAY
      KDSCT=KDSCT+1
      DO 5050 L=1,100
 5050 DSRAY(L)=0.0
      KDS=1
 5055 NNDS=NNDS+1
      IF(NNDS-NDS) 5070,5070,5060
 5060 WRITE (6,5065) DSX1,DSX2,DS1,DSRES1,DSRES2,DSRES
      LL=18
      GO TO 1490
 5070 CONTINUE
      GO TO (2401,2402,2404,12411,2405,2407,2409),IDW
C     $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
C
C    COMPUTE NEXT APPROXIMATION TO DS.
C
   91 NIS=NNDS
      IBLX=1
      DS=DS1
      DSAVE=DS1
      NNDS=0
      GO TO 100
 1490 NSTMT=1490
      RETURN
  100 NSTMT=100
      RETURN
  500 NDIAG=1
      CALL OUTPUT(NNN,LPGCT,NGBO)
```

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      NSTMT=110                                                         SEC64500
      RETURN                                                            SEC64510
 5065 FORMAT(1H0,7X,51HNO DS CONVERGENCE.  COULD DETECT NO SIGN CHANGE  SEC64520
     1IN ,34HRESIDUALS OF F(DS).  VALUES FOLLOW  /(10X,1P6E15.6))       SEC64530
 9001 FORMAT(1H0,10X,20HNEGATIVE VBMSQ,SECT6 /(1X,1P9E15.6))            SEC64540
 9136 FORMAT(1H0,7X,17HOUTSIDE RANGE OF  , A6,7H TABLE.,5X,             SEC64550
     14HT = ,1PE12.4,5X,4HP = ,F12.4)                                   SEC64560
 9310 FORMAT(1H0,7X,12HNEGATIVE PAB)                                    SEC64570
 9312 FORMAT(1H0,7X,12HNEGATIVE PBB)                                    SEC64580
 9318 FORMAT(1H0,7X,17HOUTSIDE RANGE OF ,A6,7H TABLE.,5X,               SEC64590
     14HT = ,1PE12.4,5X,4HP = ,F12.4)                                   SEC64600
 9320 FORMAT(1H0,7X,12HINFINITE PAB)                                    SEC64610
 9333 FORMAT(1H0,7X,14HNONPOSITIVE FB)                                  SEC64620
 9352 FORMAT(1H0,7X,24HCOULD NOT CONVERGE ON T3)                        SEC64630
 9491 FORMAT(1H ,1P10E13.4)                                             SEC64640
      END                                                               SEC64650
                      SUBROUTINE THROAT                                 THRO0010
      COMMON TZZZAY                                                     THRO0020
      DIMENSION TZZZAY(11200)                                           THRO0030
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP            THRO0050
C     IT MUST BE THE FIRST COMMON BLOCK                                 THRO0060
      COMMON    A      , ABAR   , ALAM   , ALPHAB , ALPHA  , ALPHMB ,   THRO0070
     1          ALPHS  , AM     , AP     , AS     , AT     , BA     ,   THRO0080
     2          BB     , BETAB  , BETAMB , BETA   , BETAG  , BM     ,   THRO0090
     3          C      , C1     , CAG1   , CAGMB  , CAG    , CALMB  ,   THRO0100
     4 CBG1   , CAL    , CAGR   , CBGMB  , CBG    , CBLMB  , CBL        THRO0110
      COMMON    CCMS   , CDP    , CD     , CFIM   , CFIMS  , CFOM   ,   THRO0120
     6          CFOMS  , CGMB   , CGM    , CGMS   , CLMB   , CLM    ,   THRO0130
     7          CLMS   , CSAVE  , D      , D2     , DA     , DATE   ,   THRO0140
     8          DD     , DELIM  , DELI   , DELIS  , DELOM  , DELO   ,   THRO0150
     9          DELOS  , DELSI  , DELSO  , DELPM  , DELP   , DELV2      THRO0160
      COMMON    DEMAGB , DEMAG  , DEMBGB , DEMUG  , DEMGD  , DIST   ,   THRO0170
     1          DLSIS  , DLSOS  , DO     , DP1    , DP     , DRAY   ,   THRO0180
     2          DPI    , DRC    , DR     , DS1    , DSAVE  , DSLIM  ,   THRO0190
     3          DSMAX  , DSMIN  , DSRAY1 , DSRAY  , DSRES1 , DSRES2 ,   THRO0200
     4          DSRES  , DS     , DSX1   , DSX2   , DTG1   , DTHB   ,   THRO0210
      COMMON    DTG    , DTHI   , DTHO   , DTL1   , DTLB   , DTL    ,   THRO0220
     6          DT     , DVBSQ  , DVGSQ  , DVLSQ  , DX     , DYI    ,   THRO0230
     7          DYO    , EB     , EBB    , EMAGB  , EMAG   , EMBGB  ,   THRO0240
     8          EMBG   , EMGB   , EMG    , EMGS   , EMLB   , EMLM   ,   THRO0250
     9          EML    , EMLS   , EMT    , EPO    , FLUFP  , FUK        THRO0260
      COMMON    H      , HJS    , HKAG   , HKBG   , HKGM1  , HKGM2  ,   THRO0270
     1          HKGM   , HKGMS  , HLA1   , HLAM   , HLA    , HLAS   ,   THRO0280
     2          HLS1   , HLSM   , HLS    , HLSS   , HM     , HMS    ,   THRO0290
     3          HOPE   , HT     , IACV   , IBLM   , IBLA   , IGM    ,   THRO0300
     4          IGH    , INT    , ISET   , IZERO  , K      , K1     ,   THRO0310
      COMMON    K2     , KAP    , KDSCT  , KDS    , KL     , KR1    ,   THRO0320
     6          KP     , KTDCT  , KTB    , KTP1   , KKP    , L      ,   THRO0330
     7          L1     , L2     , LCT1   , LCT2   , LL     , LPRCT  ,   THRO0340
     8          LSW    , MBU    , MFFO   , MFP    , MGEO   , MM     ,   THRO0350
     9 N      , MOP    , MTHT   , NACV   , N9     , NCLK   , NCTS       THRO0360
      COMMON    NDIAG  , NDS    , NGS    , NIB    , NIS    , NLST   ,   THRO0370
     1          NNA    , NNB    , NNDS   , NNN    , NNP    , NN     ,   THRO0380
     2          NNSOO  , NNSO   , NNS    , NP     , NSO    , NS     ,   THRO0390
     3          P      , P10    , P11    , PAB    , PAMB   , PA     ,   THRO0400
     4          PAS    , PBB    , PBMB   , PBOB   , PBO    , PB     ,   THRO0410
      COMMON    PBS    , PHIAB  , PHIPA  , PHI    , PINT   , PL     ,   THRO0420
     6          PL1    , PO     , PS     , PT     , Q      , QIP    ,   THRO0430
     7          R1     , RA     , RAS    , RAKO   , RAX    , RB     ,   THRO0440
     8          RC     , RDSLIM , RDELOM , RDIMS  , RDOMS  , REP    ,   THRO0450
     9          REM    , REMS   , RESLIM , RESO   , RHOZ   , RHOGB      THRO0460
      COMMON    RHOG   , RHOGS  , RHOLB  , RHOLM  , RHOL   , RHOLS  ,   THRO0470
     1          RIM    , RI     , RM     , ROALB  , ROAL   , ROBLB  ,   THRO0480
     2          ROBL   , ROM    , RO     , R      , RSLIM  , RS     ,   THRO0490
     3          RVB    , RV     , RVS    , S      , S1     , S2     ,   THRO0500
     4          S3     , S4     , SA     , SB     , SGM    , SIG      THRO0510
      COMMON    SIGS   , SMIN   , SMJ1   , SMJ2   , SMLC   , SMLD   ,   THRO0520
     6          SMLE   , SMLP   , SMLG   , SM     , SOJ1   , SOJ2   ,   THRO0530
     7          SOP    , SO     , SOGM   , SS     , SSM    , SZO    ,   THRO0540
     8          T      , TB     , TBRAY  , TBRAY1 , TGMB   , TGO    ,   THRO0550
     9          TG     , TGS    , THIN   , THIO   , THT    , THIS       THRO0560
      COMMON    THOB   , THOO   , THO    , THOS   , TK     , TKT    ,   THRO0570
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     1          TLMB    , TLO     , TL      , TLS     , TST     , TWIS    ,
     2          TWIMS   , TWOM    , TWOMS   , V1      , V2      , VAR     ,
     3          VBD     , VBDS    , VB*     , VBXSQ   , VB      , VBSQ    ,
     4          VBS     , VGO     , VG      , VGSQ    , VGS     , VIAG    ,
      COMMON    VIALB   , VIAL    , VIBG    , VIBLG   , VIBL    , VIGM    ,
     6          VIGMS   , VILB    , VILM    , VILMS   , VLM     , VLO     ,
     7          VL      , VLSQ    , VLS     , VS      , VSS     , WAGB    ,
     8          WAG     , WAGS    , WAL     , WBGB    , WBG     , WBGS    ,
     9          WBL     , WGO     , WG      , WGS     , WIM     , WIMS    ,
      COMMON    WOM     , WOMS    , X       , X10     , X11     , XCLR    ,
     1          XINT    , XP      , XS      , XX      , XXA     , YI      ,
     2          YIS     , YO      , YOS     , ZZZ     , NSTMT
      DIMENSION PL(10)
       DIMENSION NDRAY(75)
      DIMENSION DATE(5),CASE(3),OID(8),XP(2,75),PL1(10),
     1          C(6),AP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TPRAY(100),TBRAY
     21(100),DRAY(75),HT(14),DINT(8)
      EQUIVALENCE (NDRAY(1),DRAY(1))
      IF(NSTMT-110)1,110,1
    1 CALL DUMP
C
C
C     PRINT THROAT CONDITIONS.
C
  110 WRITE (6,9110)
      NSTMT=1999
      WRITE (6,1001) XS,PS,RS,VBS,AS,TGS,TLS,VGS,VLS
 1175 WRITE (6,1002) VSS,SS,DD,RVS,WAS,ALPHS,BETAS,
     1          ZMGS,ZMLS
 1176 WRITE (6,1003) RHOGS,RHOLS,WAGS,WBGS,WGS,
     1          PAS,PBS,HLAS,HLBS
 1177 WRITE (6,1004) SIGS,CGMS,CLMS,VIGMS,VILMS,
     1          HKGMS,HKMS,CDMS,HMS
 1178 WRITE(6,1007) YOS,WOMS,THOS,DELOS,DLSOS,
     1          PDOMS,CPOMS,TWOMS,VBDS
      IF(MGEO-1)497,1180,497
C
C     LINE 8 OF OUTPUT CONTAINS ADDITIONAL QUANTITIES COMPUTED  FOR
C        ANNULAR NOZZLE.
C
 1180 WRITE (6,1008) YIS,WIMS,THIS,DELIS,DLSIS,RDIMS,
     1          CFIMS,TWIMS
  497 NSTMT=497
      RETURN
C
C     FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.
C
 1001 FORMAT(1H0,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,
     12HTL,12X,2HVG,12X,2HVL,/,6X,1P9E14.4)
 1002 FORMAT(1H0,12X,2HVS,13X,1HS,13X,1HD,12X,2HRV,12X,2HPA,9X,
     15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,1P7E14.4)
 1003 FORMAT(1H0,11X,4HRHOG,11X,4HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,
     112X,2HPA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,1P9E14.4)
 1004 FORMAT(1H0,9X,5HSIGMA,11X,3HCGM,11X,3HCLM,11X,4HVIGM,10X,
     14HVILM,11X,3HKGM,11X,3HKLM,11X,3HCDM,12X,2HHM,/,6X,1P9E14.4)
 1007 FORMAT(1H0,12X,2HYO,11X,3HWOM,11X,3HTHO,10X,4HDELO,9X,5HDEL*O,
     19X,5HPDOCM,10X,4HCPOM,10X,4HTWOM,11X,3HVBD,/,6X,1P9E14.4     )
 1008 FORMAT(1H0,12X,2HYI,11X,3HWIM,11X,3HTHI,10X,4HDELI,9X,5HDEL*I,9X,
     15HRDIM,10X,4HCFIM,10X,4HTWIM,/,6X,1P8E14.4)
 9110 FORMAT(1H0,7X,24HTHROAT CONDITIONS FOLLOW)
      END
                    SUBROUTINE DIAGNO
      COMMON TZZZAY
      DIMENSION TZZZAY(11200)
C     THE ABOVE COMMON BLOCK FOR SUBROUTINES TABLE AND INTRP
C     IT MUST BE THE FIRST COMMON BLOCK
      COMMON    A       , ABAR    , ALAM    , ALPHAB  , ALPHA   , ALPHMD  ,
     1          ALPHS   , AM      , AP      , AS      , AT      , BB      ,
     2          BB      , BETAB   , BETAMB  , BETA    , BETAS   , BM      ,
     3          C       , C1      , CAG1    , CAGMB   , CAG     , CALMB   ,
     4 CBG1   , CAL     , CASE    , CBGMB   , CBG     , CBLMB   , CBL     ,
      COMMON    CDMS    , CDP     , CD      , CFIN    , CFIMS   , CFOM    ,
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6          CPOMS  , CGMB   , CGM    , CGMS   , CLMB   , CLM    ,      DIAG0130
7          CLMS   , CSAVE  , D      , D2     , DA     , DATE   ,      DIAG0140
8          DD     , DELIM  , DELI   , DELIS  , DELOM  , DELO   ,      DIAG0150
9          DELOS  , DELSI  , DELSO  , DELRM  , DELT   , DELV2  ,      DIAG0160
  COMMON   DEMAGB , DEMAG  , DEMBGB , DEMBG  , DEMGB  , DINT   ,      DIAG0170
1          DLSIS  , DLSOS  , DO     , DP1    , DP     , DRAY   ,      DIAG0180
2          DRI    , DRO    , DS     , DS1    , DSAVE  , DSLIM  ,      DIAG0190
3          DSMAX  , DSMIN  , DSRAY1 , DSRAY  , DSRES1 , DSRES2 ,      DIAG0200
4          DSRES  , DS     , DSX1   , DSX2   , DTG1   , DTGU   ,      DIAG0210
  COMMON   DTG    , DTHI   , DTHO   , DTL1   , DTLB   , DTL    ,      DIAG0220
6          DT     , DVBSQ  , DVGSQ  , DVLSQ  , DX     , DYI    ,      DIAG0230
7          DYO    , EB     , EDS    , EMAGB  , EMAG   , EMBGB  ,      DIAG0240
8          EMBG   , EMGB   , EMG    , EMGS   , EML3   , EMLM   ,      DIAG0250
9          EML    , EMLS   , EMT    , ESO    , FLEEP  , FUX    ,      DIAG0260
  COMMON   H      , HJI    , HKAG   , HKBG   , HKGM1  , HKGM2  ,      DIAG0270
1          HKGM   , HKGMS  , HLA1   , HLAM   , HLA    , HLAS   ,      DIAG0280
2          HLB1   , HLBM   , HLB    , HLBS   , HM     , HMS    ,      DIAG0290
3          HOPE   , HT     , IACV   , IBLW   , IBLX   , IBW    ,      DIAG0300
4          IJH    , IST    , ISPT   , IZERO  , K      , K1     ,      DIAG0310
  COMMON   K2     , KAP    , KDSCT  , KDS    , KL     , KR1    ,      DIAG0320
6          KR     , KTBCT  , KTB    , KXP1   , KXP    , L      ,      DIAG0330
7          L1     , L2     , LCT1   , LCT2   , LL     , LPGCT  ,      DIAG0340
8          LSW    , MBU    , MPRO   , MEP    , MGEO   , MM     ,      DIAG0350
9 N      , MOP    , MPHT   , NACY   , NB     , NCLK   , NCTS   ,      DIAG0360
  COMMON   NDIAG  , NDS    , NGG    , NTB    , NTS    , NLST   ,      DIAG0370
1          NNA    , NNB    , NNDS   , NNN    , NNP    , NN     ,      DIAG0380
2          NN300  , NNSO   , NNS    , NP     , NSO    , NS     ,      DIAG0390
3          P      , P10    , P11    , PAB    , PAMB   , PA     ,      DIAG0400
4          PAS    , PBB    , PBMB   , PBOB   , PBO    , PB     ,      DIAG0410
  COMMON   PBS    , PHIAB  , PHIBA  , PHI    , PINT   , PL     ,      DIAG0420
6          PL1    , PO     , PS     , PT     , Q      , QID    ,      DIAG0430
7          R1     , RA     , RAS    , RAYO   , RAX    , RB     ,      DIAG0440
8          RC     , RDSLIM , RDELOM , RDIMS  , RDOMS  , RF     ,      DIAG0450
9          REM    , REMS   , RELLIM , RE30   , RESZ   , RHOGB  ,      DIAG0460
  COMMON   RHOG   , RHOGS  , RHOLB  , RHOLM  , RHOL   , RHOLS  ,      DIAG0470
1          RIM    , RI     , RM     , ROALB  , ROAL   , ROOLB  ,      DIAG0480
2          ROBL   , ROM    , RO     , R      , RSLIM  , RS     ,      DIAG0490
3          RVB    , RV     , RVS    , S      , S1     , S2     ,      DIAG0500
4          S3     , S4     , SA     , SB     , SGN    , SIG    ,      DIAG0510
  COMMON   SIGS   , SMIN   , SMJ1   , SMJ2   , SMLC   , SMLD   ,      DIAG0520
6          SMLE   , SMLF   , SMLG   , SM     , SOJ1   , SOJ2   ,      DIAG0530
7          SOP    , SO     , SOSM   , SS     , SZM    , SZO    ,      DIAG0540
8          T      , TB     , TBRAY  , TBRAY1 , TGMB   , TGO    ,      DIAG0550
9          TG     , TGS    , THIM   , THIO   , THI    , THIS   ,      DIAG0560
  COMMON   THOM   , THOO   , THO    , THOS   , TK     , TKT    ,      DIAG0570
1          TLMB   , TLO    , TL     , TLS    , TST    , TWIM   ,      DIAG0580
2          TWIMS  , TWOM   , TWOMS  , V1     , V2     , VAL    ,      DIAG0590
3          VBD    , VBDS   , VBM    , VBMSQ  , V3     , VGSD   ,      DIAG0600
4          VBS    , VGO    , VG     , VGSD   , VGS    , VIAG   ,      DIAG0610
  COMMON   VIALB  , VIAL   , VIBG   , VIBLB  , VIBL   , VIGM   ,      DIAG0620
6          VIGMS  , VILB   , VILM   , VILMS  , VLM    , VLO    ,      DIAG0630
7          VL     , VLSO   , VLS    , VS     , VSS    , WAGB   ,      DIAG0640
8          WAG    , WAGS   , WAL    , WBGB   , WBG    , WBGS   ,      DIAG0650
9          WBL    , WGB    , WG     , WGS    , WIM    , WIMS   ,      DIAG0660
  COMMON   WOM    , WOMS   , X      , X10    , X11    , XCLK   ,      DIAG0670
1          XINT   , XP     , XS     , XX     , XXA    , YI     ,      DIAG0680
2          YIS    , YO     , YOS    , ZZZ    , NSTMT                  DIAG0690
  DIMENSION PL(10)                                                     DIAG0700
   DIMENSION NDRAY(75)                                                 DIAG0710
  DIMENSION DATE(5),CASZ(3),DID(8),XP(2,75),PL1(10),                   DIAG0720
 1         C(6),YP(2,75),XXA(8),DSRAY(100),DSRAY1(100),TBRAY(100),TBRAYDIAG0730
 21(100),DRAY(75),HT(18),DINT(8)                                       DIAG0740
  EQUIVALENCE (NDRAY(1),DRAY(1))                                       DIAG0750
  IF(NSTMT-497)1,497,2                                                 DIAG0760
1 CALL DUMP                                                            DIAG0770
2 IF(NSTMT-529)1,529,1                                                 DIAG0780
497 NSTM1=9999                                                         DIAG0790
  IF(NDIAG-1)10,498,10                                                 DIAG0800
498 DO 499 I=1,75                                                      DIAG0810
  DRAY(I)=99999.                                                       DIAG0820
499 CONTINUE                                                           DIAG0830
  LSW=0                                                                DIAG0840
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```
      GO TO(501,502,503,504,505,506,507,508,509,510,511,512,513,514,
     1      515,516,517,518,519,520,521,522,523,524,525,526,527,528,
     2      529),LL
C
C     DIAGNOSTIC OUTPUT.    ENTRY IS MADE TO SET CERTAIN
C        SETS OF OUTPUT VALUES INTO THE ARRAY DRAY DEPENDING
C        ON THE VALUE OF LL, WHICH IS SET IN VARIOUS POINTS THROUGHOUT
C        THE MAIN PROGRAM.
C
  529 DRAY(54)=DEF
      NSTM=9999
      DRAY(45)=VILB
  528 DRAY(53)=Q
      DRAY(39)=ABAR
      DRAY(47)=RHOLB
  527 DRAY(46)=RHOGB
  526 DRAY(39)=TB
  525 DRAY(44)=CMLB
      DRAY(43)=EMGB
      DRAY(37)=RJ
  524 DRAY(42)=BETAB
      DRAY(41)=ALPHAB
      DRAY(50)=WGB
      DRAY(49)=WBGB
  523 DRAY(48)=WAGB
  522 DRAY(52)=PBB
  521 DRAY(51)=PAB
  520 DRAY(70)=CFIM
      DRAY(69)=RDELIM
      DRAY(71)=TWIM
      DRAY(61)=CFOM
      DRAY(60)=RDELOM
      DRAY(36)=HM
      DRAY(35)=CD
  519 DRAY(34)=REM
  518 DRAY(63)=VBO
      DRAY(56)=WOM
      DRAY(59)=DELSO
      DRAY(58)=DELO
      DRAY(57)=THO
      DRAY(62)=TWOM
      DRAY(68)=DELSI
      DRAY(67)=DELI
      DRAY(66)=THI
      DRAY(55)=WIM
  517 DRAY(5)=A
      DRAY(12)=D
      DRAY(28)=SIG
  516 DRAY(14)=RA
      DRAY(9)=VL
      DRAY(4)=VG
  515 DRAY(1)=X
      DRAY(10)=CLM
      DRAY(23)=CGM
      DRAY(31)=VIGM
      DRAY(32)=VILM
      DRAY(33)=HKGM
      GO TO 1511
  514 DRAY(33)=HKGM
      DRAY(32)=VILM
  513 DRAY(31)=VIGM
      DRAY(29)=CGM
      DRAY(30)=CLM
  512 DRAY(63)=VBO
      DRAY(56)=WOM
      DRAY(59)=DELSO
      DRAY(58)=DELO
      DRAY(57)=THO
      DRAY(62)=TWOM
      DRAY(68)=DELSI
      DRAY(67)=DELI
      DRAY(66)=THI
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```
      DRAY(65)=WIN
      DRAY(5)=A
      DRAY(12)=D
      DRAY(28)=SIG
      DRAY(14)=PA
      DRAY(9)=VL
      DRAY(8)=VG
      DRAY(1)=X
 1511 DRAY(55)=YO
      DRAY(54)=YI
  511 DRAY(11)=S
      DRAY(4)=VB
      DRAY(10)=VS
      DRAY(5)=A
      DRAY(27)=HLB
  510 DRAY(26)=HLA
  509 DRAY(13)=RV
      DRAY(18)=EML
      DRAY(17)=EMG
      DRAY(20)=RHOL
  508 DRAY(19)=RHOG
      DRAY(3)=R
  507 DRAY(16)=BETA
      DRAY(15)=ALPHA
      DRAY(23)=WG
      DRAY(22)=WBG
  506 DRAY(21)=WAG
  505 DRAY(25)=PB
  504 DRAY(24)=PA
  503 DRAY(7)=TL
  502 DRAY(6)=TG
  501 DRAY(2)=P
      NDRAY(72)=NNA
      NDRAY(73)=NIS
      NDRAY(74) = NIB
      IF(NDIAG-1)540,550,540
  540 WRITE (11) DRAY
      NNN=NNN+1
      DRAY(12)=7.0
C     WRITE(18) (DRAY(J),J=1,10)
      MM=MM+1
      GO TO 63
C
C  DIAGNOSTIC OUTPUT - VARIABLES NOT YET COMPUTED THIS
C    ITERATION ARE SET TO 10E5. PRINT OUT NINE LINES
C    OF OUTPUT.
C
  550 WRITE (6,1001)  (DRAY(I),I=1,9)
  551 WRITE (6,1002)  (DRAY(I),I=10,18)
  552 WRITE (6,1003)  (DRAY(I),I=19,27)
  553 WRITE (6,1004)  (DRAY(I),I=28,36)
  554 WRITE (6,1005)  (DRAY(I),I=29,45)
  555 WRITE (6,1006)  (DRAY(I),I=46,54)
  556 WRITE (6,1007)  (DRAY(I),I=55,63)
  557 WRITE (6,1008)  (DRAY(I),I=64,71)
  558 CONTINUE
      WRITE (6,1009) NNA,NIS,NIB
   10 NSTMT=10
      RETURN
   63 NSTMT=63
      RETURN
C
C   FORMAT STATEMENTS FOR 9-LINE PERMANENT OUTPUT.
C
 1001 FORMAT(1H0,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,
     12HTL,12X,2HVG,12X,2HVL,/,6X,9F06.4)
 1002 FORMAT(1H0,12X,2HVS,13X,1HS,13X,1HD,12X,2HRV,12X,2HPA,9X,
     15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,9E14.4)
 1003 FORMAT(1H0,11X,3HRHOG,11X,3HRHOL,11X,3HWAG,11X,3HWBG,12X,2HWG,
     112X,2HPA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,9E14.4)
 1004 FORMAT(1H0,9X,5HSIGMA,11X,3HCGM,11X,3HCLM,10X,4HVIGM,10X,
     14HVILM,11X,3HKGM,11X,3HREM,11X,3HCDM,12X,2HHM,/,6X,10E14.4)
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1005 FORMAT(1HO,12X,2HPB,12X,2HAB,12X,2HTB,11X,3HRVB,9X,5HALPHB,        DIAG2300
    19X,5HBETAB,11X,3HMGB,11X,3HMLB,10X,4HVILB,/,6X,9E14.4  )          DIAG2310
1006 FORMAT(1HO,10X,4HROGB,10X,4HROLB,10X,4HWAGB,10X,4HWBGB,            DIAG2320
    111X,3HWGP,11X,3HPAB,11X,3HPBB,13X,1HQ,11X,3HREF,/,6X,9E14.4)       DIAG2330
1007 FORMAT(1HO,12X,2HYO,11X,3HWOM,11X,3HTHO,10X,4HDELO,9X,5HDEL*O,     DIAG2340
    19X,5HREDOM,10X,4HCFOM,10X,4HTWOM,11X,3HVBD,/,6X,9E14.4)            DIAG2350
1008 FORMAT(1HO,12X,2HYI,11X,3HWIN,11X,3HTHI,10X,4HDELI,9X,5HDEL*1,9X,  DIAG2360
    15HREDIN,10X,4HCFIN,10X,4HTWIN,/,6X,8E14.4)                         DIAG2370
1009 FORMAT(1HO ,10X ,3HNNA  ,9X ,3HNIS  ,9X, 3HNIB /2X, 3(6X,I6))      DIAG2380
C1032 FORMAT(1H1,120X,5HPAGE ,I3,/,1X,15HREAL TWO-PHASE ,               DIAG2390
C    1      26H TWO-COMPONENT NOZZLE FLOW,// )                          DIAG2400
      END                                                               DIAG2410
      SUBROUTINE WRITE      (DVGSQ,DTL,RHOLM,DVLSQ,DEMAG,DEMBG,         WRIT0010
     1      DELV2,EMG,HLA1,CAG1,DELT,HLB1,CBG1,SM,AM,DM,DX,DS)          WRIT0020
      WRITE (6,9231) DVGSQ,DTL,RHOLM,DVLSQ,DEMAG,DEMBG,                 WRIT0030
     1      DELV2,EMG,HLA1,CAG1,DELT,HLB1,CBG1,SM,AM,DM,DX,DS           WRIT0040
      RETURN                                                            WRIT0050
9231 FORMAT(1HO,12X,5HDVGSQ,14X,3HDTL,12X,5HRHOLM,12X,5HDVLSQ,12X,      WRIT0060
    15HDEMAG,12X,5HDEMBG,12X,5HDELV2,/,1X,12E17.6,//,15X,3HEMG,14X,     WRIT0070
    1   3HLA1,13X,4HCAG1,13X,4HDELT,14X,3HLB1,13X,4HCBG1,               WRIT0080
    1      15X,2HSM,/,1X,7E17.6,//,                                     WRIT0090
    2      16X,2HAM,15X,2HDM,15X,2HDX,15X, 2HDS,/,1X,7E17.6)            WRIT0100
      END                                                               WRIT0110
      SUBROUTINE OUTPUT(N,LPG,NGZO)                                     OUTP0010
C SUBROUTINE TO READ SAVED PRINT LINES FROM LOGICAL                     OUTP0020
C     TAPE 27 AND PRINT THEM ON FORTARAN OUTPUT TAPE.                   OUTP0030
      DIMENSION DRAY(75),NDRAY(75)                                      OUTP0040
      EQUIVALENCE (DRAY(1),NDRAY(1))                                    OUTP0050
      REWIND 11
      L=1                                                               OUTP0070
    1 IF(N)99,99,2                                                      OUTP0080
    2 READ (11)DRAY                                                     OUTP0090
      IF(L)5,5,4                                                        OUTP0100
    4 WRITE (6,1032) LPG                                                OUTP0110
      LPG=LPG+1                                                         OUTP0120
      L=0                                                               OUTP0130
       GO TO 6                                                          OUTP0140
    5 WRITE (6,998)                                                     OUTP0150
      L=1                                                               OUTP0160
    6 WRITE  (6,1001)  (DRAY(I),I=1,9)
      WRITE  (6,1002)  (DRAY(I),I=10,18)                                OUTP0180
      WRITE  (6,1003)  (DRAY(I),I=19,27)                                OUTP0190
      WRITE  (6,1004)  (DRAY(I),I=28,36)                                OUTP0200
      WRITE  (6,1005)  (DRAY(I),I=37,45)                                OUTP0210
      WRITE  (6,1006)  (DRAY(I),I=46,54)                                OUTP0220
      WRITE  (6,1007)  (DRAY(I),I=55,63)                                OUTP0230
      IF(NGZO) 7,8,7                                                    OUTP0240
    7 WRITE  (6,1008)  (DRAY(I),I=64,71)                                OUTP0250
    8 CONTINUE                                                          OUTP0260
      WRITE  (6,1009)  (NDRAY(I),I=72,74)                               OUTP0270
       N=N-1                                                            OUTP0280
      GO TO 1                                                           OUTP0290
   99 REWIND 11                                                         OUTP0300
      RETURN                                                            OUTP0310
  998 FORMAT(1HO,///  )                                                 OUTP0320
C1000 FORMAT(6X,9E14.4)                                                  OUTP0330
1001 FORMAT(1HO,13X,1HX,13X,1HP,13X,1HR,12X,2HVB,13X,1HA,12X,2HTG,12X,  OUTP0340
    12HTL,12X,2HVG,12X,2HVL,/,6X,9E14.4)                                OUTP0350
1002 FORMAT(1HO,12X,2HGS,13X,1HS,11X,1HD, 12X,2HRV,12X,2HRA,9X,         OUTP0360
    15HALPHA,10X,4HBETA,12X,2HMG,12X,2HML,/,6X,9E14.4)                  OUTP0370
1003 FORMAT(1HO,11X,3HROG,11X,3HROL,11X,3HWAG,11X,3HWBG,12X,2HWG,       OUTP0380
    112X,2HPA,12X,2HPB,12X,2HLA,12X,2HLB,/,6X,9E14.4)                   OUTP0390
1004 FORMAT(1HO,9X,5HSIGMA,11X,3HCGM,11X,3HCLM,10X,4HVIGM,10X,          OUTP0400
    14HVILM,11X,3HKGM,11X,3HREM,11X,3HCDM,12X,2HHM,/,6X,9E14.4)
1005 FORMAT(1HO,12X,2HPB,12X,2HAB,12X,2HTB,11X,3HRVB,9X,5HALPHB,        OUTP0420
    19X,5HBETAB,11X,3HMGB,11X,3HMLB,10X,4HVILB,/,6X,9E14.4)             OUTP0430
1006 FORMAT(1HO,10X,4HROGB,10X,4HROLB,10X,4HWAGB,10X,4HWBGB,            OUTP0440
    111X,3HWGP,11X,3HPAB,11X,3HPBB,13X,1HQ,11X,3HREF,/,6X,9E14.4)       OUTP0450
1007 FORMAT(1HO,12X,2HYO,11X,3HWOM,11X,3HTHO,10X,4HDELO,9X,5HDEL*O,     OUTP0460
    19X,5HREDOM,10X,4HCFOM,10X,4HTWOM,11X,3HVBD,/,6X,9F14.4)            OUTP0470
1008 FORMAT(1HO,12X,2HYI,11X,3HWIN,11X,3HTHI,10X,4HDELI,9X,5HDEL*1,9X,  OUTP0480
    15HREDIN,10X,4HCFIN,10X,4HTWIN,/,6X,8E14.4)                         OUTP0490
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 1009 FORMAT(1H0,10X,3HNNA,9X,3HNIS,9X,3HNIB            /,2X,
     1      3(6X,I6))
 1032 FORMAT(1H1,120X,5HPAGE ,I3,/,1X,15HREAL TWO-PHASE ,
     1       26H TWO-COMPONENT NOZZLE FLOW,// )
      END
      SUBROUTINE XPTBL(XP)
C  SUBROUTINE TO PRINT OUT XP TABLE C
      DIMENSION XP(2,75)
  792 L1=1
      L2=8
  794 WRITE (6,793)
C  PRINT OUT NEW X(P) TABLE
  795 WRITE (6,909)  (XP(1,MT),MT=L1,L2)
      WRITE (6,917)  (XP(2,MT),MT=L1,L2)
      IF (L2-72) 796,797,798
  796 L1=L1+8
      L2=L2+8
      GO TO 795
  797 L1=L1+8
      L2=L2+3
      GO TO 795
  798 RETURN
  793 FORMAT(1H1,//,50X,14HNEW X(P) TABLE,///)
  909 FORMAT(1H0,3X,5HPRESS,1X,1P8E15.4)
  917 FORMAT(1H ,7X,1HX,1X,1P8E15.4)
      END
      SUBROUTINE TABLE
C   GENERATE NOZZLE FLOW TABLE TAPE SUBROUTINE
C
C
      DIMENSION TVAR(14,2,50),C(6),XVAR(4,35),TSAV1(35,4,35),
     1        TSAV2(35,4,35)
      COMMON TSAV1,TSAV2
      DO 1 I=1,14
      DO 1 J=1,2
      DO 1 K=1,50
      TVAR(I,J,K)=1.0E5
    1 CONTINUE
      DO 2 L=1,35
      DO 2 I= 1,4
      DO 2 K=1,35
      TSAV1(L,I,K) = 100000.
      TSAV2(L,I,K) = 100000.
    2 CONTINUE
      DO 25 I = 1,4
      DO 25 J=1,35
C     THIS CHANGE TO MAKE THE MAX DIMENSION CONSISTENT WITH THE DIMENSIO
      XVAR (I,J) = 100000.
   25 CONTINUE
    3 L=1
      I=1
      K=1
      ICARD=0
    4 READ (5,901)  (C(M),M=1,6)
      ICARD=ICARD+1
      IF (C(3))5,6,5
    6 IF(C(2)-1.0) 11,11,5
    5 DO 10 M = 1,5,2
      IF(C(M)+C(M+1) - 199999.)8,13,13
    8 TSAV1(L,I,K) = C(M)
      TSAV2(L,I,K) = C(M+1)
      IF(K-35) 9,9,26
    9 K = K+1
   10 CONTINUE
      GO TO 4
   26 WRITE (6,900) I,L,K
      GO TO 37
   11 XV = C(2)
      XVAR(I,L) = C(1)
      GO TO 4
   13 IF(XV) 15,14,15
   14 L = L+1
```

```
      K=1
      IF(L-35) 4,4,27
C     THIS CHANGE TO MAKE THE MAX DIMENSION CONSISTENT WITH THE DIMENSIO
   15 IF(I-4) 16,17,17
   16 L=1
      I = I + 1
      K=1
      GO TO 4
   27 WRITE (6,927) I
      GO TO 37
   17 CONTINUE
      REWIND 12
      WRITE (12) XVAR
      WRITE (12) TSAV1
      WRITE (12) TSAV2
C  NEXT CARD IS FIRST CARD OF TVAR ARRAY
      DO 36 I=1,14
      K=1
   29 READ (5,901) (C(L),L=1,6)
      ICARD=ICARD+1
      DO 34 L=1,5,2
      IF(C(L)+C(L+1)-199999.)32,30,30
   30 TVAR(I,1,K)=100000.
      TVAR(I,2,K)=100000.
      GO TO 38
   32 TVAR(I,1,K)=C(L)
      TVAR(I,2,K)=C(L+1)
      IF(K-50) 33,37,37
   33 K=K+1
   34 CONTINUE
      GO TO 29
   38 CONTINUE
   36 WRITE (12) TVAR
      CSAVE=1.0
      READ (5,901) (C(L),L=1,6)
      ICARD=ICARD+1
      DO 1036   I=1,6
 1036 CSAVE = CSAVE + C(I)
      IF(CSAVE) 37,1037,37
   37 CALL INTRP(V,20,1.0,P)
      CALL DUMP
      CALL EXIT
 1037 CONTINUE
      ENDFILE 12
      REWIND 12
      RETURN
  900 FORMAT(1H0,7X,19HERROR IN INPUT DATA,3I6)
  901 FORMAT (6E12.6)
  927 FORMAT(1H0,7X,36HEXCEEDING MAXIMUM TEMPERATURE INPUT ,
     17HFOR  N =,I3)
      END
      SUBROUTINE INTRP(VAR,N,T,P)
C
C     IF N=0, READ IN ALL TABLES, SET UP T ARRAY, AND EXIT.
C     IF N= 20 WRITE OUT ALL TABLES AND EXIT.
C     IF N=1 THRU 4, GET APPROPRIATE TABLES FROM TAPE,
C       INTERPOLATE FOR VALUE OF VAR AND EXIT.
C     IF N=5 THRU 13, INTERPOLATE FOR VALUE OF VAR AND EXIT.
C
      DIMENSION TVAR(14,2,50),TVAR1(35,4,35),TVAR2(35,4,35)
     1         ,TRAY(4,35),H(14)
      COMMON TVAR1,TVAR2,TVAR
      IDN=0
      IF(N) 1,1,10
    1 K=1
      REWIND 12
      READ (12) TRAY
      READ (12) TVAR1
      READ (12) TVAR2
C
C     T ARRAY HAS BEEN SET UP, NO. OF T RECORDS (K) IS SET, NOW
C            PROCEED TO BRING IN PERMANENT ARRAYS.
```

```
C
      READ (12) TVAR
      RETURN
   10 IF(N-20) 100,12,11
   11 WRITE (6,911)
      CALL EXIT
C  WRITE OUT TABLES FOR N=20, T IS PAGE COUNT.
   12 CALL ADATA
      LCT1=0
      LPGCT=T
      WRITE (6,920) LPGCT
      LPGCT=LPGCT+1
      DO 30 L=1,14
   13 NT=1
   14 TEST1=TVAR(L,1,NT)+TVAR(L,2,NT)
      IF(TEST1-2.0*99999.) 15,15,16
   15 NT=NT+1
      IF(NT-50) 14,14,1000
   16 TVAR(L,1,NT)=0.0
      TVAR(L,2,NT)=0.0
      IF(NT-1) 515,520,515
C  NO INPUT THIS TABLE
  520 WRITE (6,9520) H(L)
      LCT1 = LCT1+4
      GO TO 530
  515 NT=NT-1
      WRITE (6,916) H(L)
      L1=1
      L2=AMIN0(8,NT)
      LT=1
   18 WRITE (6,918) H(L), (TVAR(L,2,LK),LK=L1,L2)
      WRITE (6,919) (TVAR(L,1,LK),LK=L1,L2)
      IF(L2-NT) 19,20,20
   19 L1=L1+8
      L2=AMIN0(L2+8,NT)
      LT=LT+1
      GO TO 18
   20 LCT1=LT*3+3+LCT1
  530 IF(LCT1-52) 30,21,21
   21 WRITE (6,920) LPGCT
      LPGCT=LPGCT+1
      LCT1=1
   30 CONTINUE
      REWIND 12
      DATA H(1)/4H CAG/
      DATA H(2)/4H CBG/
      DATA H(3)/4H WAG/
      DATA H(4)/4H WBG/
      DO 50 L=1,4
      IF (TRAY (L,1)-99999.) 29,29,50
   29 WRITE (6,920) LPGCT
   31 WRITE (6,915) H(L)
      LPGCT=LPGCT+1
      LCT1=1
      DO 45 KK=1,35
      IF (TRAY (L,KK)-99999.) 32,32,45
   32 WRITE (6,934) TRAY(L,KK)
      LCT1=LCT1+3
      NCT=1
   34 TEST1=TVAR1(KK,L,NCT)+TVAR2(KK,L,NCT)
      IF(TEST1-2.0*99999.) 35,36,36
   35 NCT=NCT+1
      IF(NCT-35) 34,34,1000
   36 NCT=NCT-1
      L1=1
      L2=AMIN0(8,NCT)
   37 CONTINUE
   38 DO 63 LT=L1,L2
      IF(TVAR2(KK,L,LT)-100000.) 63,60,63
   60 TVAR1(KK,L,LT)=0.0
      TVAR2(KK,L,LT)=0.0
   63 CONTINUE
```

```
      WRITE (6,938) H(L),(TVAR2(KK,L,LT),LT=L1,L2)
   39 WRITE (6,939) (TVAR1(KK,L,LT),LT=L1,L2)
      LCT1=LCT1+3
      IF(LCT1-52)66,65,65
   65 WRITE (6,920) LPGCT
      LPGCT=LPGCT+1
      LCT1=3
   66 IF(L2-NCT)40,41,41
   40 L1=L1+8
      L2=AMIN0(L2+8,NCT)
      GO TO 38
   41 IF(LCT1-52)45,42,42
   42 WRITE (6,920) LPGCT
      LPGCT=LPGCT+1
      LCT1=3
   45 CONTINUE
   50 CONTINUE
      IF(IBW-1) 1047,1046,1047
 1046 N=0
 1047 RETURN
C  N=1 THRU 19 - INTERPOLATE ROUTINE
  100 IF(N-4) 101,101,150
  101 DO 104 I=1,35
      IF(TBAY(N,I)-T) 104,105,105
  104 CONTINUE
      GO TO 120
  105 IF(I-1) 106,120,106
  106 IM1=I-1
      TK=TBAY(N,I)
      TK1=TBAY(N,IM1)
      DO 107 J1=1,35
      IF(TVAR1(IM1,N,J1)-P) 107,107,108
  107 CONTINUE
      GO TO 120
  108 IF(J1-1) 109,120,109
  109 IF(TVAR1(IM1,N,J1)+TVAR2(IM1,N,J1)-2.0*99999.) 110,120,120
  110 JM1=J1-1
      DIFPT=TVAR1(IM1,N,J1)-TVAR1(IM1,N,JM1)
      DIFP1=      TVAR1(IM1,N,J1)-P
      PC1=-(DIFP1/DIFPT)*(TVAR2(IM1,N,J1)-TVAR2(IM1,N,JM1))+
     1TVAR2(IM1,N,J1)
      DO 111 J2=1,35
      IF(TVAR1(I,N,J2)-P) 111,111,112
  111 CONTINUE
      GO TO 120
  112 IF(J2-1) 113,120,113
  113 JM2=J2-1
      IF(TVAR1(I,N,J2)+TVAR2(I,N,J2)-2.*99999.) 114,120,120
  114 DIFPT=TVAR1(I,N,J2)-TVAR1(I,N,JM2)
      DIFP1=      TVAR1(I,N,J2)-P
      PC2 =-(DIFP1/DIFPT)*(TVAR2(I,N,J2)-TVAR2(I,N,JM2))+TVAR2(I,N,J2)
      VAR=(T-TK1)/(TK-TK1)*(PC2-PC1)+PC1
  130 RETURN
  120 N=0
      IHW=1
      GO TO 12
  150 N=N-4
      IF(N-15) 155,1000,1000
  155 CONTINUE
      DO 151 I=1,50
      IP=I
      IF(TVAR(N,1,I)-T) 151,151,152
  151 CONTINUE
      GO TO 120
  152 IF(TVAR(N,1,I)+TVAR(N,2,I)-2.0*99999.) 153,120,120
  153 IF(IP-1) 154,120,154
  154 IP1=IP-1
      VAR=((T-TVAR(N,1,IP1))/(TVAR(N,1,IP)-TVAR(N,1,IP1)))
     1*(TVAR(N,2,IP)-TVAR(N,2,IP1))+TVAR(N,2,IP1)
      GO TO 130
 1000 CONTINUE
      CALL OUTPUT
```

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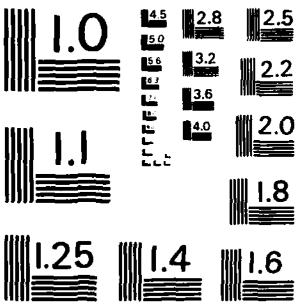
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1.6

```
      CALL DUMP
      RETURN
  911 FORMAT(1H0,7X,33HILLEGAL CALLING SEQUENCE TO INTRP)
  916 FORMAT(1H0,56X,11HINPUT TABLE,2X,A5,/)
  918 FORMAT(1H0,A6,1PE15.6)
  919 FORMAT (1H ,2X,4HTEMP,1PE15.6      )
  920 FORMAT(1H1,/,120X,4HPAGE,2X,I3)
  934 FORMAT(1H0,43X,14HTEMPERATURE = ,F12.4,//)
  938 FORMAT(1H0,3X,A6,1PE15.6)
  939 FORMAT(1H ,3X,SUPRESS ,1X, 1PE15.6)
 9520 FORMAT(1H0,/,1H0,7X,16HNO INPUT FOR TABLE, A6)
      END
C***************************************************************
      SUBROUTINE DUMP
      CALLEXIT
      RETURN
      END
C
C***************************************************************
      SUBROUTINE ADATA
      DIMENSION HT(18),H(14),HT1(18),H1(14)
      COMMON HT,H
      DATA HT1/4H CAG,4H CBG,4H HAG,4H HBG,4H CAL,
     1         4H CBL,4H  LA,4H  LB,4H PBO,4HROAL,
     2         4HROBL,4H KAG,4H KBG,4HVIAL,4HVIBL,
     3         4HVIAG,4HVIBG,4H SIG/
      DATA H1/4H CAL,4H CBL,4H HLA,4H HLB,4H PBO,
     1        4HROAL,4HROBL,4H KAG,4H KBG,4HVIAL,
     2        4HVIBL,4HVIAG,4HVIBG,4H SIG/
      DO 10 I=1,18
         HT(I)=HT1(I)
   10 CONTINUE
      DO 20 I=1,14
         H(I)=H1(I)
   20 CONTINUE
      RETURN
      END
```

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